UNCLASSIFIED

AD NUMBER
AD824273
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to DoD only; Administrative/Operational Use; DEC 1967. Other requests shall be referred to Marshall Space Flight Center, NASA, Huntsville, AL.**
AUTHORITY
USAEDC ltr, 12 Jul 1974

THIS PAGE IS UNCLASSIFIED

AEDC-TR-67-192

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-02)

D. E. Franklin

ARO, Inc.

December 1967

LARGE ROCKET FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-02)

D. E. Franklin

ARO, Inc.

AF - AEDC
Arnold AFS Tenn

FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine, and Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on July 14, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on August 18, 1967.

This technical report has been reviewed and is approved.

Harold Nelson, Jr.	Leonard T. Glaser
Captain, USAF	Colonel, USAF
AF Representative, LRF	Director of Test
Directorate of Test	

ABSTRACT

Four firings, and one engine start to expiration of the ignition phase timer, of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4. The firings were accomplished during test period J4-1801-02 at pressure altitudes from 97,000 to 106,000 ft at engine start. The objectives of the test were to evaluate S-IVB/S-V start condition effects on (1) gas generator and augmented spark igniter chamber ignition characteristics and (2) fuel pump stall characteristics during start tank blowdown for J-2 engine J-2052. Engine thermal conditions predicted for the J-2 engine flight configuration first burn, and restarts after one and two orbits, were simulated. Satisfactory engine operation was obtained. The accumulated engine firing duration was 70.8 sec.

CONTENTS

APPENDIXES

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start; time at which helium control and ignition phase solenoids are energized
GG	Gas generator
LOVT	Main oxidizer valve position
MFV	Main fuel valve
MOV	Main oxidizer valve
PU	Propellant utilization valve
STDV	Start tank discharge valve
TGGO	Gas generator outlet temperature
t_0	Time at which opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, indication of time duration of engine vibration measurement in excess of 150 g rms at frequencies between 960 and 9000 Hz

SUBSCRIPTS

e	Exit
f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine (S/N J-2052) using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The results of the last test period are reported in Ref. 1. The five firings reported herein were conducted during test period J4-1801-02 on July 14, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate J-2 engine S-IVB/S-V start condition effects on (1) the gas generator and augmented spark igniter chamber ignition characteristics and (2) fuel pump stall characteristics during start tank blowdown. These firings were accomplished at pressure altitudes ranging from 97, 000 to 106, 000 ft at engine start, with predicted thermal conditions for first burns and one and two orbit restarts. Data collected to accomplish the test objectives are presented herein. Copies of all data obtained during the test have been previously supplied to the sponsor, and copies are on file at AEDC.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 Rocket Engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225, 000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of the major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 2) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting flange to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage, axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel

lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct), before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine, in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility vent system.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lb_f-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series

with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 3.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, pneumatic regulator, and main oxidizer valve closing control line and second-stage actuator. Helium was routed internally through the tubular-walled thrust chamber and crossover duct and externally over the pneumatic regulator and main oxidizer valve closing control line and second-stage actuator.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and

periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Engine side loads were measured with dual-bridge, strain-gage-type load cells which were laboratory calibrated before installation. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers, load cells, and resistance temperature transducer units, (2) voltage substitution for the thermocouples, (3) frequency substitution for shaft speeds and flowmeters, and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance, potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6.

The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions (Ref. 4) were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, pneumatic regulator, main oxidizer valve closing control line, and main oxidizer valve second-stage actuator. The engine component conditioning system

utilized a liquid hydrogen-helium heat exchanger to provide the chilled helium for component conditioning.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Four firings, and one engine start to expiration of the ignition phase timer, were conducted during test J4-1801-02 on July 14, 1967, for a total firing duration of 70.8 sec. All firings were in support of the S-IVB/S-V J-2 engine developmental program. Thermal conditioning of the engine and engine components (crossover duct, main oxidizer valve second-stage actuator, main oxidizer valve closing control line, and pneumatic package) was accomplished to simulate the flight engine thermal conditioning predicted for (1) J-2 engine first burn and (2) 90-min (one orbit) and 180-min (two orbit) restarts. A propellant utilization valve excursion from null to the full-closed position (at t_0 + 10 sec) was conducted on the 30-sec firings 02A and 02C, effectively changing the oxidizer-to-fuel ratio from 5.0 to 5.7. Firings 02B and 02D (each 5-sec duration) were conducted with the propellant utilization valve fully open. Firings 02A, 02C, and 02E were preceded by 3-sec fuel leads; firings 02B and 02D were preceded by 8-sec fuel leads. Specific test objectives and a brief summary of results obtained for each firing are presented as follows:

Firing	Test Objectives	Results
02A	Investigate effects of S-IVB/S-V first burn, worst-case conditions for gas generator outlet second peak temperature, augmented spark igniter erosion, and fuel pump stall characteristics during release of start tank gases	Thermal conditioning limits were closely attained. No gas generator outlet second peak temperature of any significance or augmented spark igniter erosion was observed. There were no fuel pump stall tendencies during release of start tank gases.
02B	S-IVB/S-V 180-min restart simulation with selected start tank vent and relief valve effect on worst-case gas generator outlet initial and second peak temperatures	The gas generator outlet initial peak temperature was 1690°F with no significant second peak.

Firing	Test Objectives	Results
02C	Conditions identical to firing 02A, except for a reduced start tank pressure (150 psi less than firing 02A)	As was observed during firing 02A, no significant gas generator outlet second peak temperature was observed. No low level fuel pump stall tendencies were observed; the minimum high level stall margin was observed during this firing.
02D	S-IVB/S-V 90-min restart simulation without a crossover duct purge	The gas generator outlet initial peak temperature was 2100°F with no second peak.
02E	S-IVB/S-V first burn worst-case condition for augmented spark igniter lightoff	Augmented spark igniter ignition was satisfactorily obtained.

Specific test requirements and results are summarized in Table VI. Start and shutdown times of engine valves are presented in Table VII. Included in this table are pre-firing valve times obtained from the final sequence run. The pump inlets, start tank, and helium tank pressure and temperature conditions at engine start are shown in Fig. 8.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-02A

Firing 02A was of 30-sec duration with a propellant utilization valve excursion from null to fully closed (effective oxidizer-to-fuel ratio change from 5.0 to 5.7) at t_0 + 10 sec. The firing was preceded by a 3.0-sec fuel lead. A summary of engine start requirements and test results is presented in Table VI; a history of engine component pre-fire temperature conditioning is shown in Fig. 9. The thrust chamber throat temperature was 20°F colder than specified, which would tend to increase the initial gas generator outlet temperature peak and increase the fuel pump low level stall margin.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 10. Although the test conditions for firing 02A were S-IVB/S-V worst-case conditions for gas generator outlet second peak temperature, no significant second peak was observed

(Fig. 10e). The initial gas generator outlet temperature peak was 2080°F. The absence of a second peak was attributed to the relatively short time required for the beginning of main oxidizer valve second-stage ramp, which occurred 0.979 sec after t_0. Initial main oxidizer valve second-stage movement occurred during the time engine vibrations (VSC) were observed, reached the 15-deg position, and remained at that position for 0.117 sec before resuming second-stage ramp. Thrust chamber ignition occurred 0.968 sec after t_0, and VSC were observed at t_0 + 0.975 for 14 msec. The main oxidizer valve frictional torque just before initial second-stage movement was 275 in.-lb (friction torque method of calculation is presented in Ref. 5). As can be observed in Fig. 10f, gas generator outlet temperature decreased below 800°F at shutdown but then immediately increased above 1200°F. This apparently resulted from oxidizer accumulating in the gas generator purge line and being expelled at shutdown with the helium purge. A post-test inspection indicated that tape over the gas generator oxidizer purge check valve mounting flange had not been removed before valve installation before test 02. This had no apparent effect on engine operation.

Transient fuel pump head/flow data for firing 02A were documented and compared with the stall inception curve in Fig. 11. In the particular region of investigation for this firing (start tank blowdown), a very conservative stall margin of 1875 gpm was observed. The stall margin would probably have been slightly reduced had the thrust chamber temperature been within specified limits at engine start; however, there is little doubt that the stall margin would have been very conservative.

Although firing 02A conditions were the S-IVB/S-V worst case for augmented spark igniter chamber erosion, no chamber erosion was observed during post-test inspection. Data indicated the relative magnitude of the augmented spark igniter temperature (absolute temperatures not available) was higher for firing 02A than for other test 02 firings.

A summary of start and shutdown times for engine valves during firing 02A is shown in Table VII. All valve operating times were consistent and normal, with the exception of the oxidizer turbine bypass valve opening at shutdown. Although the opening time was within specified limits, the time was longer than for other test 02 firings.

Engine chamber pressure and test capsule ambient pressure for firing 02A are shown in Fig. 12. The effects of the propellant utilization valve excursion can be observed to occur at approximately t_0 + 10 sec, at which time engine chamber pressure increased from 688 to 783 psia. Test capsule pressure was higher than normal during this test and was attributed to secondary cell flow resulting from leakage of a gaseous nitrogen control valve supplying the annular ejector.

Engine steady-state performance data are presented in Table VIII. The data presented were for a 1-sec data average of test measurements from 29 to 30 sec and were computed using the Rocketdyne PAST 640 modification zero performance computer program. Engine test measurements required by the program and the program computations are presented in Appendix IV.

The gas generator oxidizer supply line orifice was not correctly installed (Fig. 13) and may have slightly lowered engine performance. Turbine efficiencies and pressure ratios could not be calculated because of unrecoverable data required as a performance program input.

4.2.2 Firing J4-1801-02B

The 180-min restart simulation firing 02B was of 5-sec duration preceded by an 8-sec fuel lead. The propellant utilization valve position was fully open throughout the firing. A summary of engine start requirements and results is presented in Table VI; a history of engine component pre-fire temperature conditioning is shown in Fig. 14. The oxidizer-to-fuel turbine crossover duct temperature used as a guideline was 16°F colder than the minimum specified requirement, which is favorable to lower gas generator outlet initial and second peak temperatures.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 15. Thrust chamber ignition occurred 0.992 sec after t_0, with no VSC. A moderate gas generator outlet initial peak temperature of 1690°F was observed, with no significant second peak (Fig. 15e). The main oxidizer valve initial second-stage movement occurred 1.053 sec after t_0, in time to prevent a gas generator outlet second peak temperature. Once the main oxidizer valve second-stage ramp began, there was no tendency for the valve to stop at an intermediate position as occurred in firing 02A. Main oxidizer valve frictional torque just before initial second-stage movement was 345 in.-lb.

A comparison of fuel pump head/flow data with the stall inception margin is presented in Fig. 16. There were no low level stall tendencies. However, because of the relatively fast main oxidizer valve second-stage ramp time (1.652-sec), a minimum high level stall margin of about 700 gpm was observed.

A summary of start and shutdown times for engine valves during firing 02B is shown in Table VII. All times were consistent and within specified limits. Engine chamber pressure and test capsule ambient

pressures are shown in Fig. 17. An engine chamber pressure of 614 psia was attained just before shutdown. Test capsule pressure altitude at engine start was 104,000 ft.

4.2.3 Firing J4-1801-02C

Firing 02C was conducted to obtain a start tank pressure gain factor on (1) the worst-case gas generator outlet second peak temperature, (2) augmented spark igniter erosion, and (3) fuel pump stall characteristics during start tank blowdown, established in firing 02A. A start tank pressure reduction of 150 psi was specified for firing 02C with all other conditions identical to firing 02A. The firing was of 30-sec duration with a propellant utilization valve excursion to fully closed at t_0 + 10 sec; the firing was preceded by a 3-sec fuel lead. A pre-fire temperature history of thermal conditioning is shown in Fig. 18; specific values at engine start, shown with the required values, are presented in Table VI. All thermal conditioning limits having any significant effect on engine start transient were within limits.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 19. No VSC were observed during engine start. Thrust chamber ignition occurred 0.982 sec after t_0. The gas generator outlet initial peak temperature was 1840°F, which was 240°F lower than observed for firing 02A. The lower gas generator outlet initial peak temperature on firing 02C can be attributed to a lower oxidizer pressure supply to the gas generator (Fig. 20), which resulted from the lower start tank pressure. In addition, the thrust chamber temperature at t_0 was approximately 30°F warmer on firing 02C, which resulted in slightly higher fuel system resistance and increased fuel flow to the gas generator. Another factor that may have contributed to the higher gas generator outlet temperature peak on firing 02A was the colder oxidizer gas generator supply line (Table VI). There was no gas generator outlet second peak temperature of any significance on firing 02C. This can be attributed to early main oxidizer valve second-stage movement, which occurred 1.040 sec after t_0; frictional torque was 362 in.-lb just before initial second-stage movement. Second-stage ramp time was 1.677 sec, without the intermediate delay noted during firing 02A. After shutdown, the gas generator outlet temperature temporarily increased above the steady-state firing level (Fig. 19f). As was noted in the discussion for firing 02A, this apparently resulted from oxidizer accumulating in the gas generator oxidizer purge line and being expelled at shutdown with the helium purge.

Transient fuel pump head/flow data for firings 02A and 02C are compared with the stall inception line in Fig. 11. During start tank blowdown, the stall margin for firing 02C was 1500 gpm as compared to 1875 gpm for firing 02A. The lower blowdown stall margin on firing 02C can be attributed to a higher resistance to fuel flow and not totally to start tank pressure. Firing 02C demonstrated a high level stall margin of about 600 gpm, the minimum for test 02 and among the lowest for J-2 engine testing at AEDC.

A summary of start and shutdown times for engine valves for firing 02C is shown in Table VII. All valve times were within specified limits.

Engine chamber pressure and test capsule ambient pressure for firing 02C are shown in Fig. 21. The increase in chamber pressure at about t_0 + 10 sec resulted from closing the propellant utilization valve. Test capsule pressure altitude at engine start was 105,000 ft.

Engine steady-state performance for firing 02C is presented in Table VIII. The data presented were for a 1-sec data average from 29 to 30 sec. An anomaly suspected of affecting the performance data was discussed in Section 4.2.1.

4.2.4 Firing J4-1801-02D

Firing 02D was a 90-min (one orbit) restart simulation test conducted with the fuel-to-oxidizer turbine exhaust crossover duct temperature within the specified limit. The crossover duct temperature used for conditioning was 176°F at engine start and demonstrated one orbit restart capability without a crossover duct purge. The firing was of 5-sec duration with the propellant utilization valve fully open and was preceded by an 8-sec fuel lead. A summary of specified conditions for engine start and results obtained is shown in Table VI. A history of component thermal conditioning is shown in Fig. 22. All thermal conditions having any significant effect on engine transient operation were within specified limits.

Engine start and shutdown transients of selected primary engine parameters are shown in Fig. 23. Thrust chamber ignition occurred 0.958 sec after t_0, and 35 msec of VSC were observed at 0.965 sec. The gas generator outlet initial peak temperature was 2100°F (the highest of the test series) with no second peak. A second peak was not obtained because of an early main oxidizer valve second-stage initial movement, which was observed 0.974 sec after t_0 (friction torque was 149 in.-lb just before the initial move). Main oxidizer valve second-stage

initial movement occurred during the time that VSC were noted. A 15-deg position was reached during VSC and maintained for 0.192 sec before resuming second-stage ramp.

A comparison of fuel pump head/flow data with the stall margin is presented in Fig. 24. A stall margin of about 1000 gpm was observed at thrust chamber ignition.

A summary of start and shutdown times for engine valves is shown in Table VII. Engine chamber and test capsule pressures are shown in Fig. 25. Just before shutdown, engine chamber pressure was 617 psia; pressure altitude at engine start was 104,000 ft.

4.2.5 Firing J4-1801-02E

Firing 02E was an S-IVB/S-V first burn simulation test to investigate the worst case for augmented spark igniter lightoff. Specified oxidizer and fuel pump inlet pressures for engine start were 35.0 ± 1 and 46.0 ± 1 psia, respectively; the fuel pump inlet pressure was 1.6 psia below the lower limit at engine start (the vacuum in the fuel line jacket was lost, making it impossible to control pump inlet conditions within specified limits). Pre-fire temperature conditioning of engine components is shown in Fig. 26. The test was 0.485 sec in duration, terminated after expiration of ignition phase timer, as planned, and was preceded by a 3-sec fuel lead. Augmented spark igniter ignition was detected 0.387 sec after engine start; however, since the fuel pump inlet pressure was too low, this was not a worst-case test.

There was some evidence of gas generator oxidizer valve leakage during this firing. The gas generator outlet temperature sensor indicated a drop of 173°F from the time that pressurization of the oxidizer vehicle tank was accomplished until engine start.

SECTION V
SUMMARY OF RESULTS

The results of these five firings of the J-2 engine conducted on July 14, 1967, in Test Cell J-4 are summarized as follows:

1. No significant gas generator outlet second peak temperatures were observed on any firings with start conditions predicted to produce a worst-case second peak. This was attributed to rapid initial opening of the main oxidizer valve second stage.

2. Low level fuel pump stall margins were conservative for worst-case low level stall conditions. A high level stall margin of about 600 gpm was noted on firing 02C, which is the lowest margin observed at AEDC.

3. An S-IVB/S-V 90-min restart firing was successfully conducted without a crossover duct purge. The initial peak gas generator outlet temperature was 2100°F with no second peak.

4. Simulation of an S-IVB/S-V 180-min restart firing was successfully conducted using start tank conditions expected with the start tank vent and relief valve selected for the flight engine. A moderate gas generator outlet temperature, initial peak, of 1690°F was observed.

5. Worst-case conditions for augmented spark igniter chamber erosion produced no erosion.

6. Augmented spark igniter ignition was detected 0.387 sec after engine start during a firing simulating S-IVB/S-V worst-case conditions for augmented spark igniter lightoff. Conditions at engine start were slightly out of specified limits.

REFERENCES

1. Muse, W. W. and Pillow, C. E. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-01)." AEDC-TR-67-181, December 1967.

2. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

3. Test Facilities Handbook (6th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

4. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.

5. Collier, M. R. and Dougherty, N. S., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-20 through J4-1554-26)." AEDC-TR-67-145, (AD821541), October 1967.

APPENDIXES

I. ILLUSTRATIONS

II. TABLES

III. INSTRUMENTATION

IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

Fig. 1 Test Cell J-4 Complex

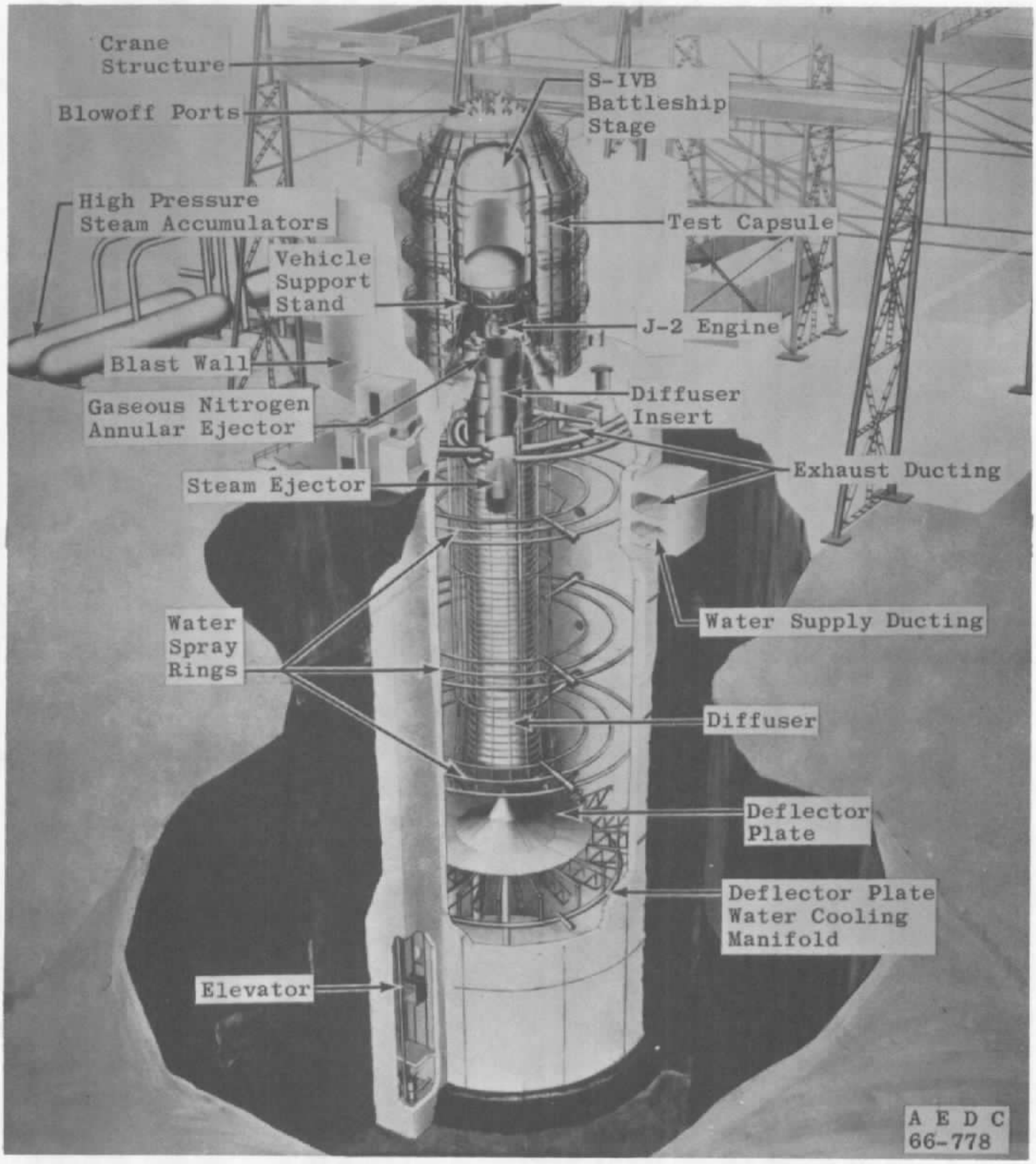


Fig. 2 Test Cell J-4, Artist's Conception

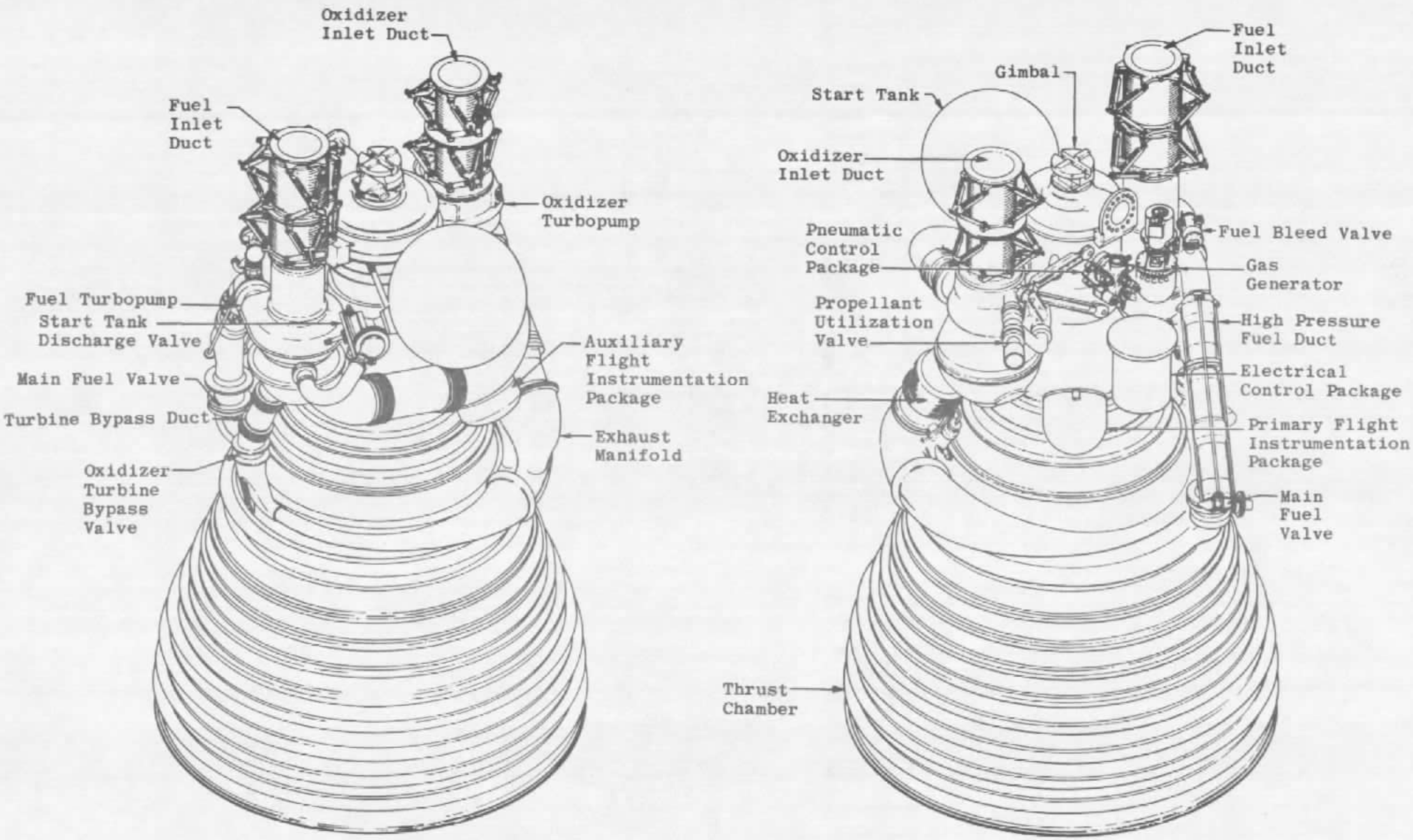


Fig. 3 Engine Details

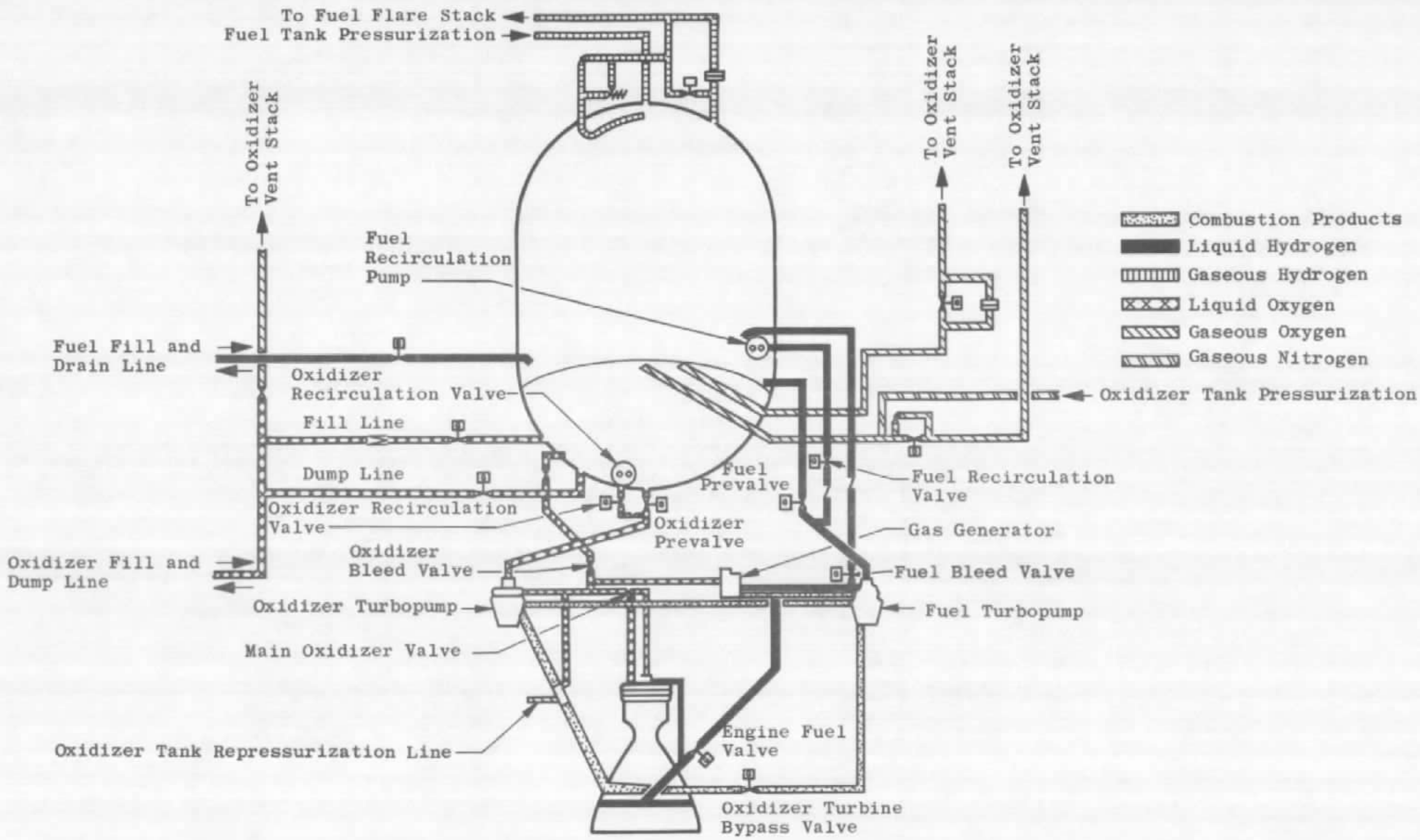


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

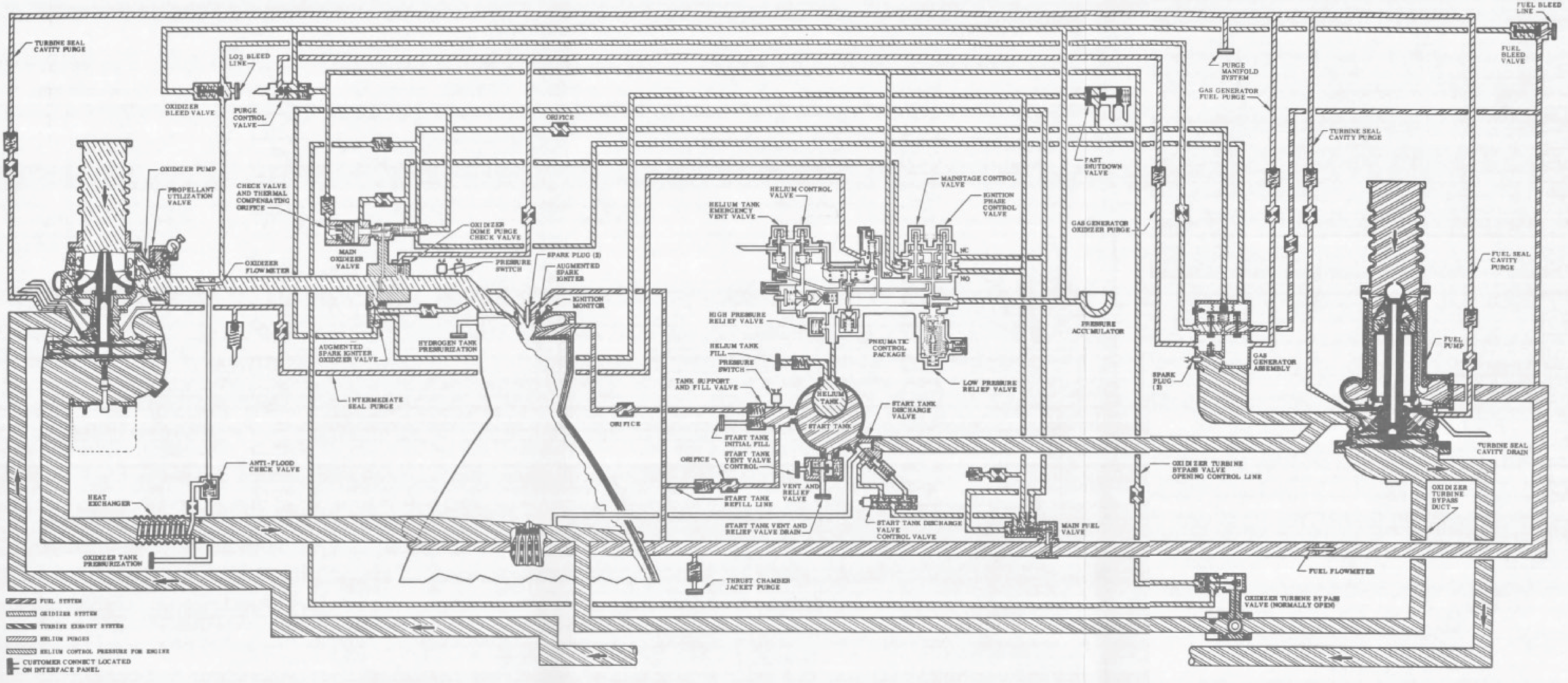


Fig. 5 Engine Schematic

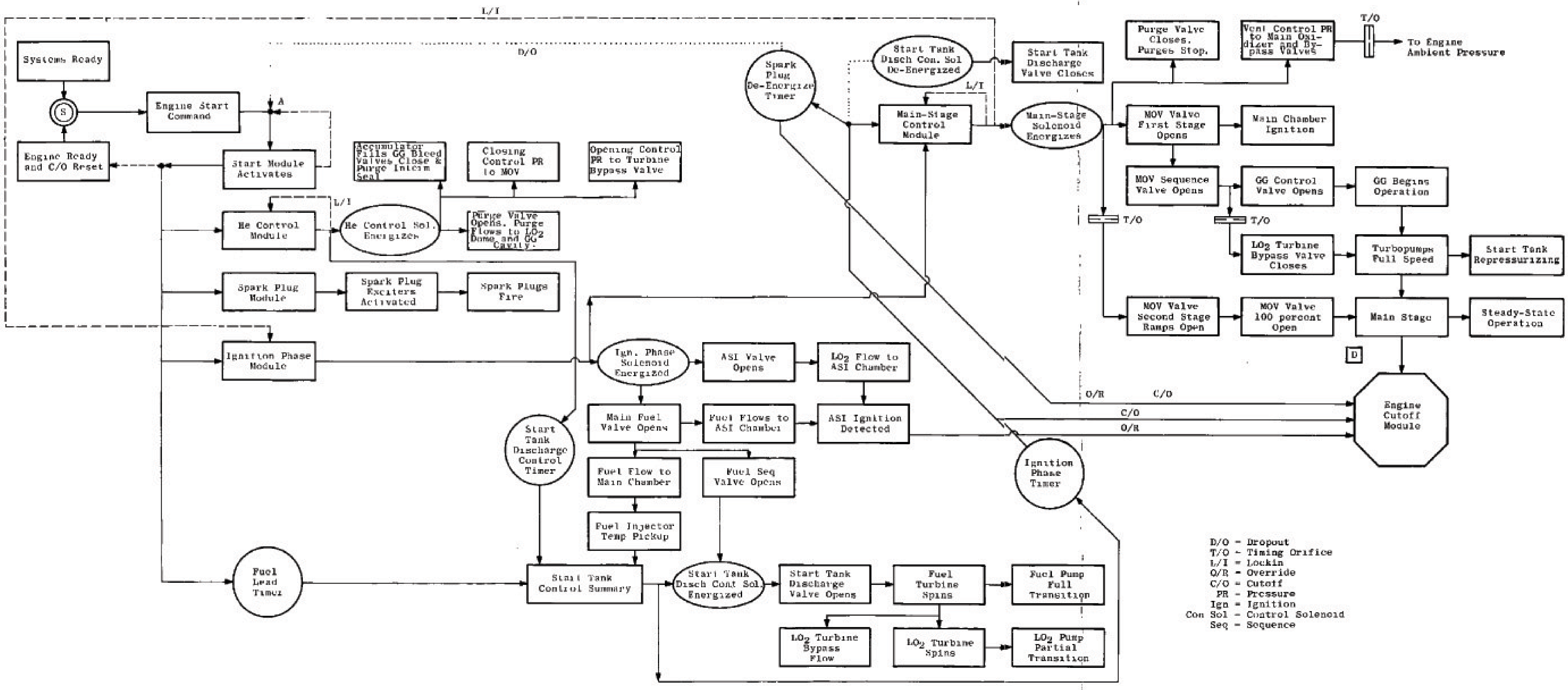
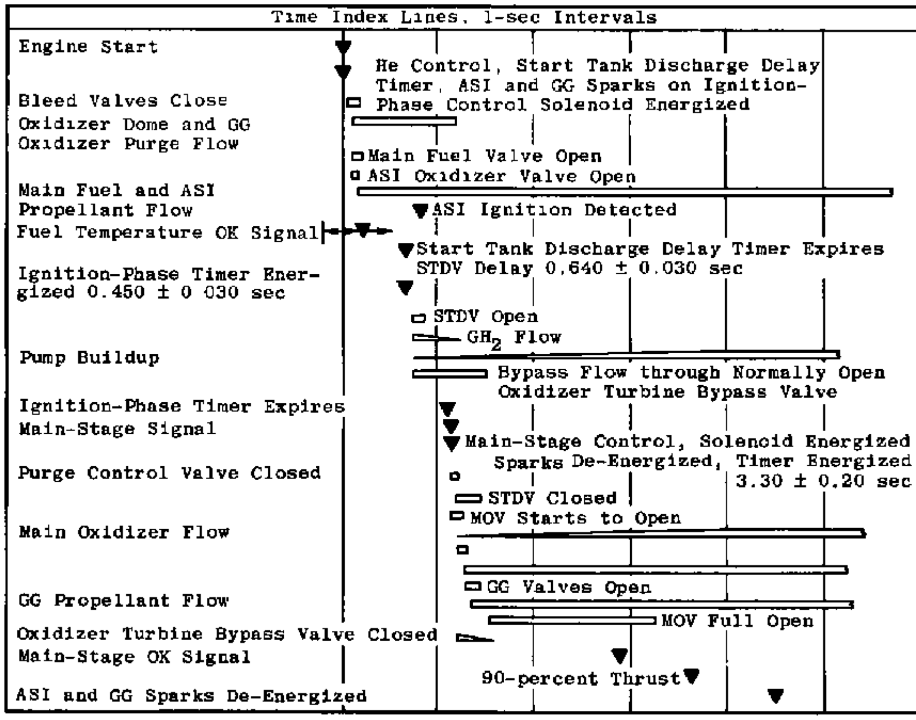
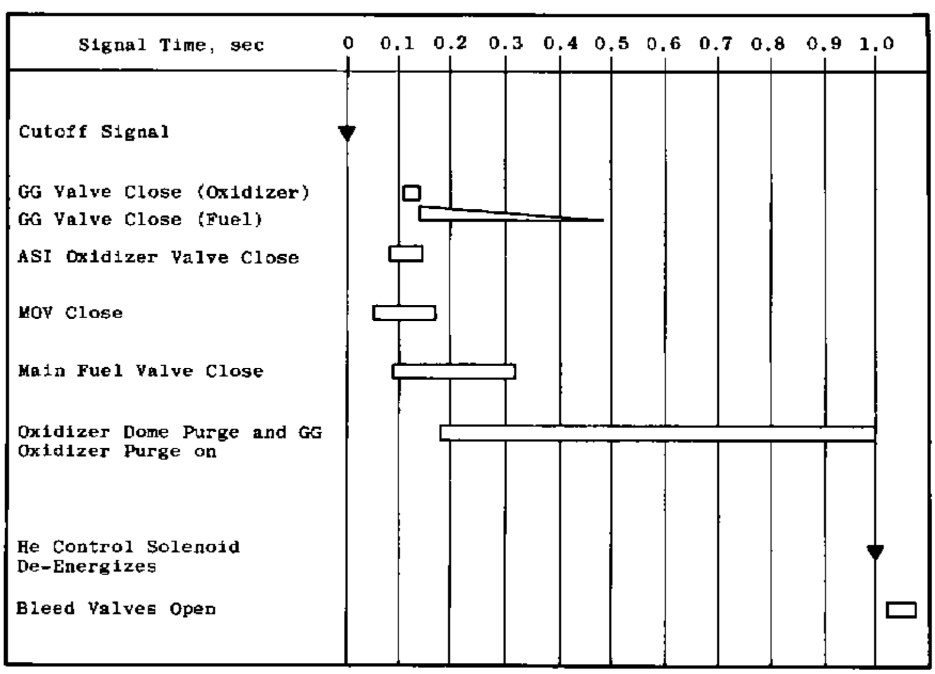


Fig. 6 Engine Start Logic Schematic

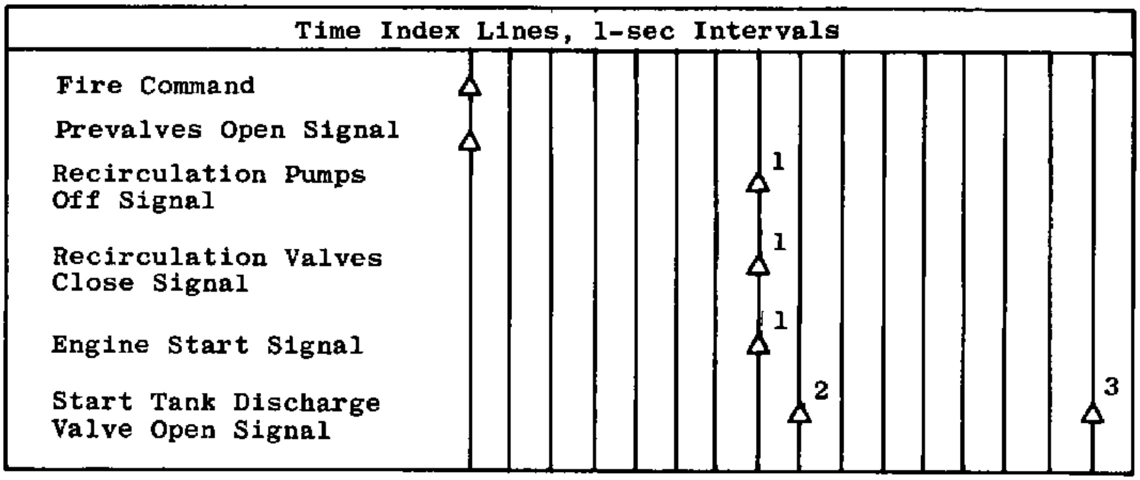


a. Start Sequence



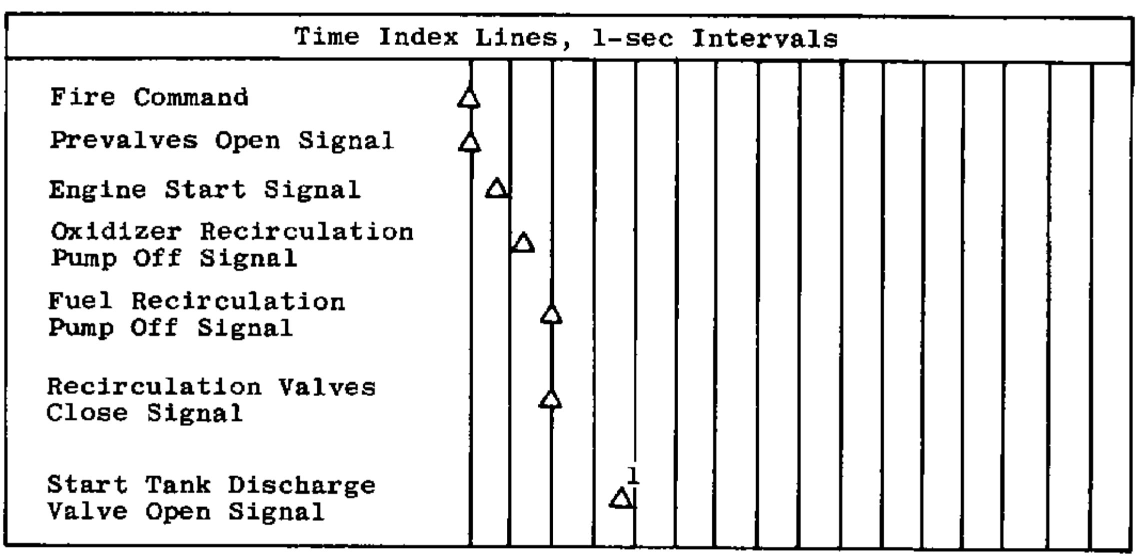
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

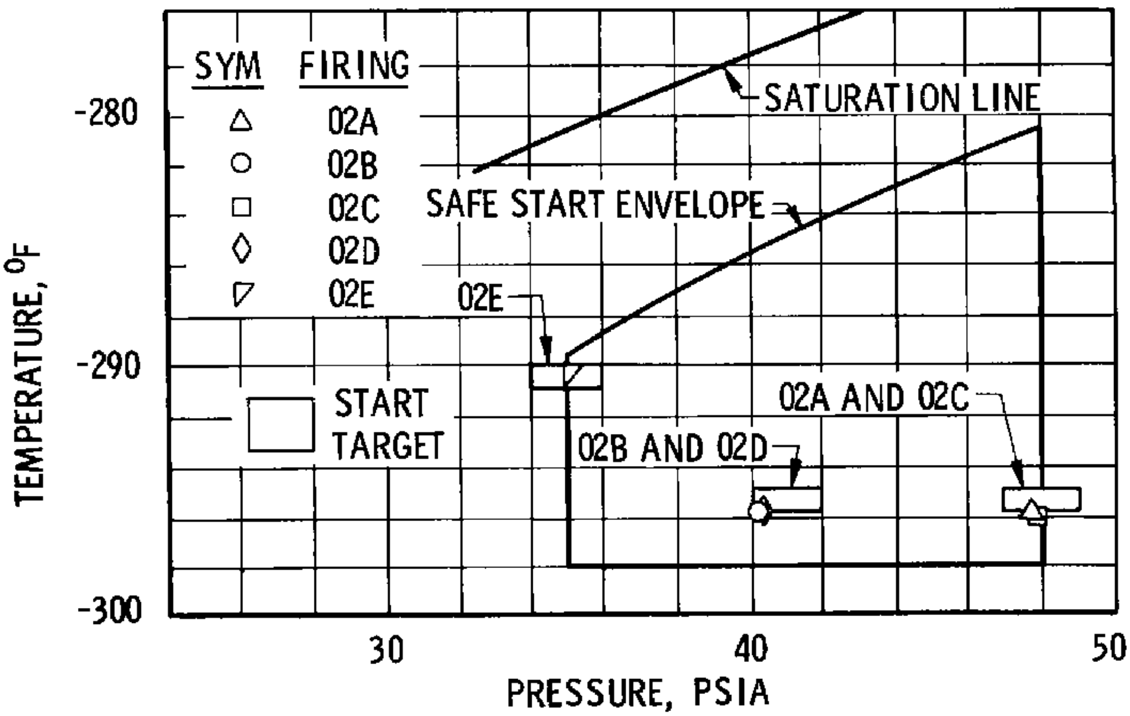
c. Normal Logic Start Sequence



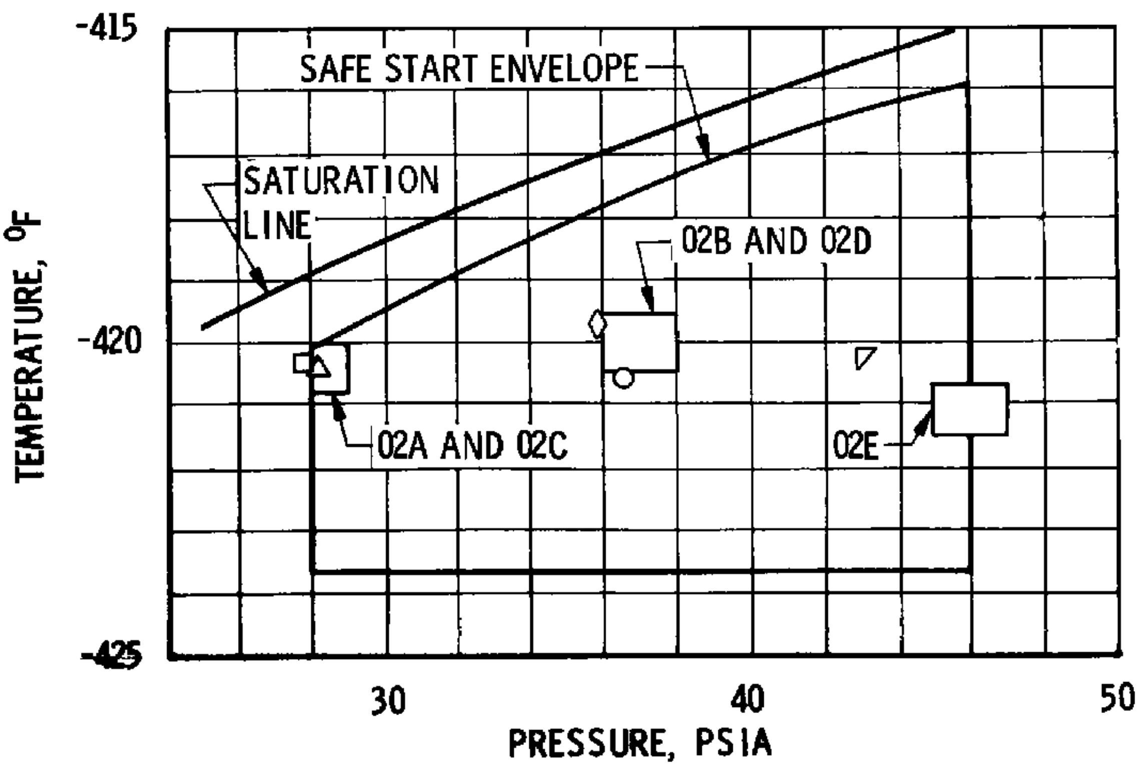
[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

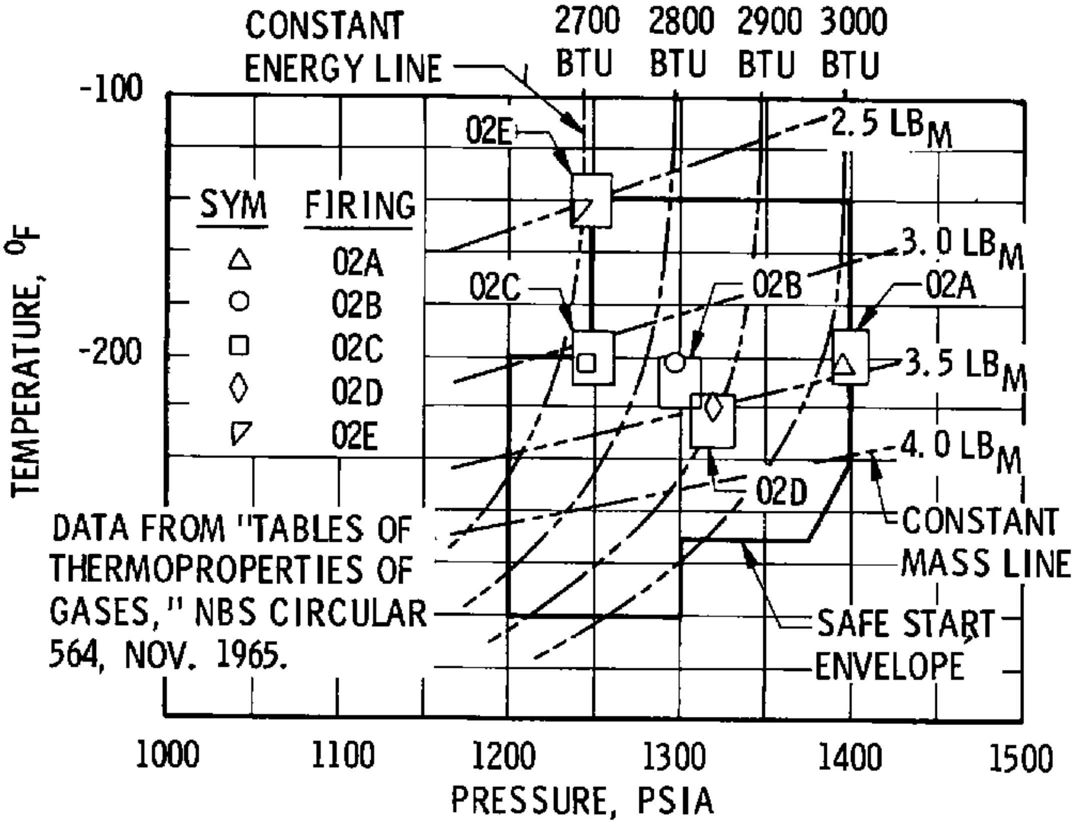


a. Oxidizer Pump Inlet

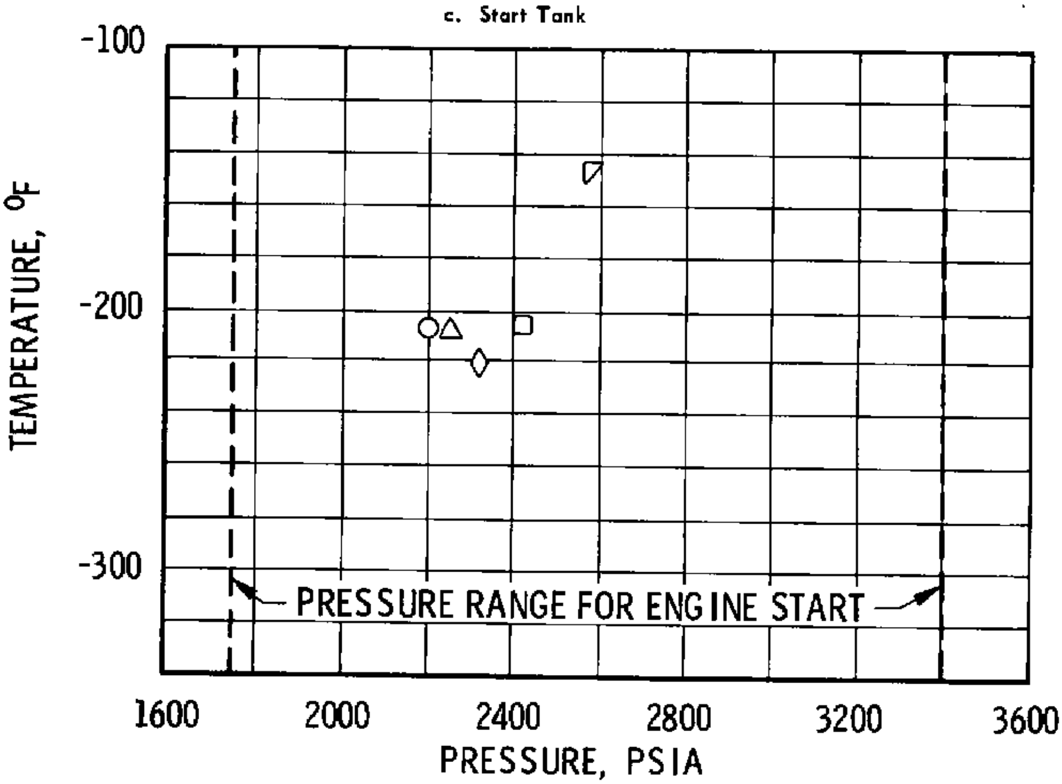


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium. Tank

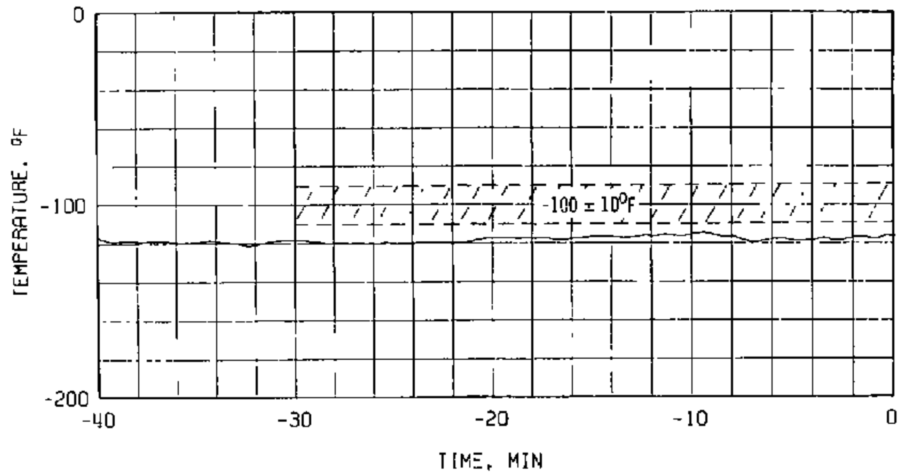


c. Start Tank

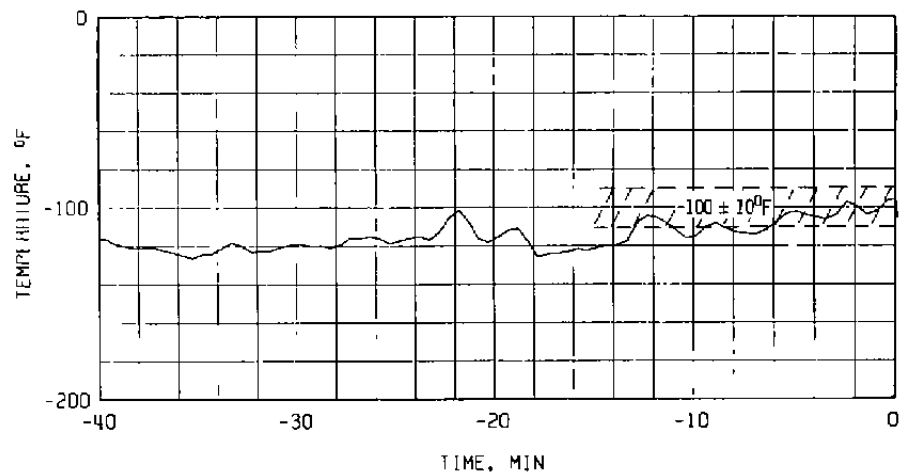


d. Helium Tank

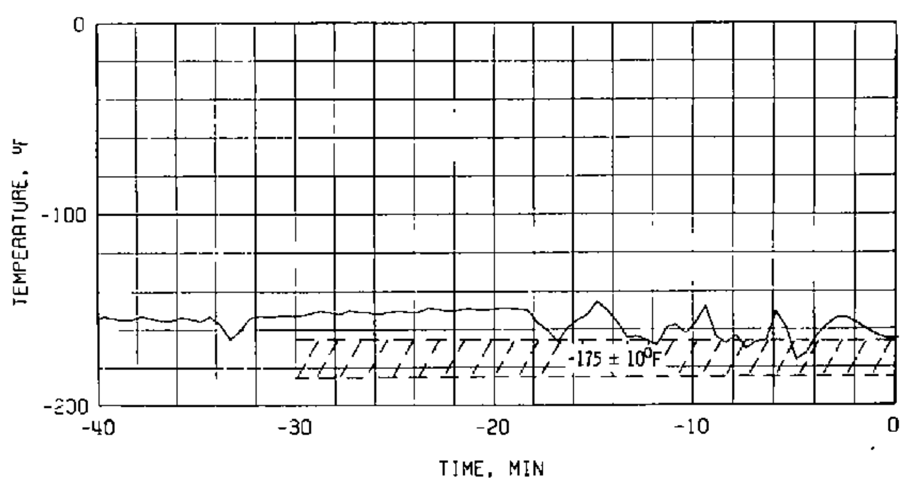
Fig. 8 Concluded



a. Pneumatic Regulator, TBHR-2

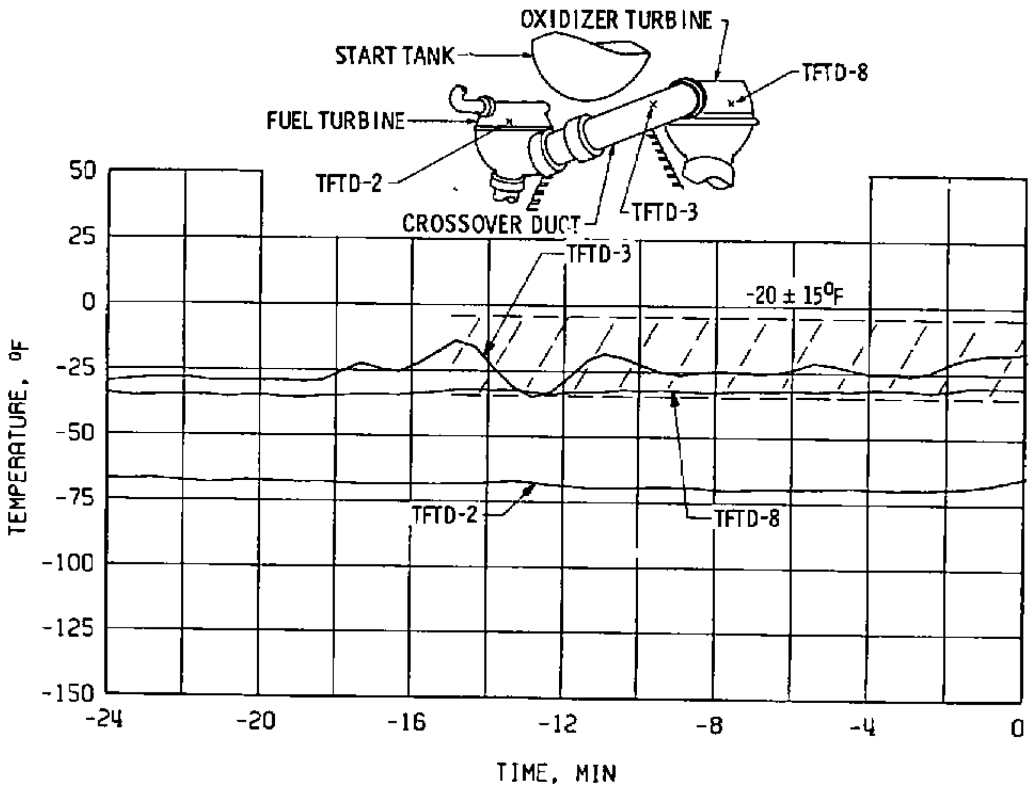


b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

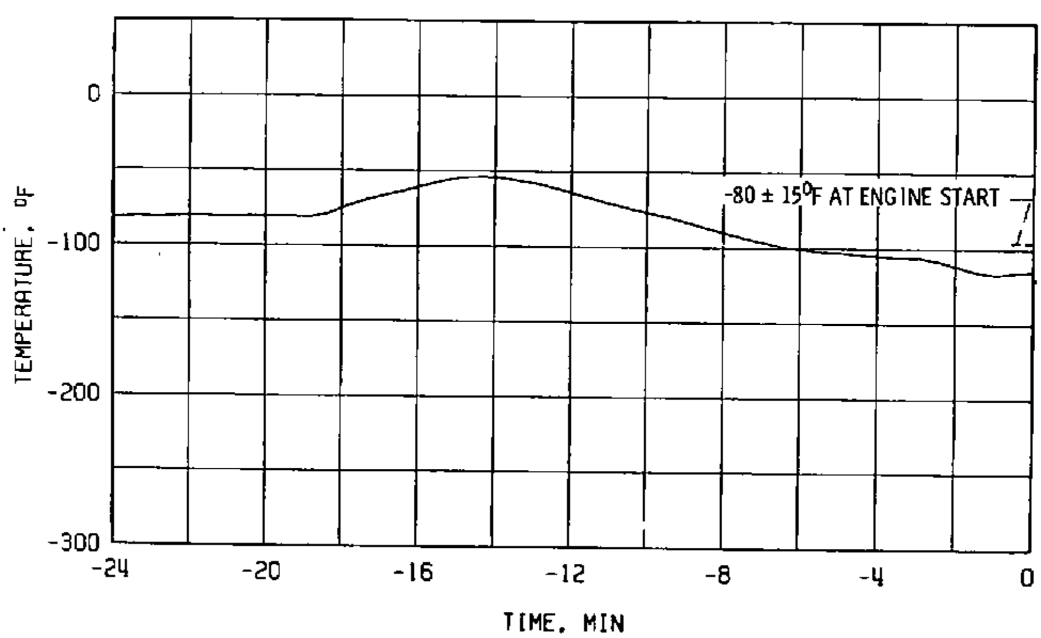


c. Main Oxidizer Valve Second-Stage Actuator, TSOVC-2

Fig. 9 History of Firing 02A Pre-Fire Temperature Conditioning

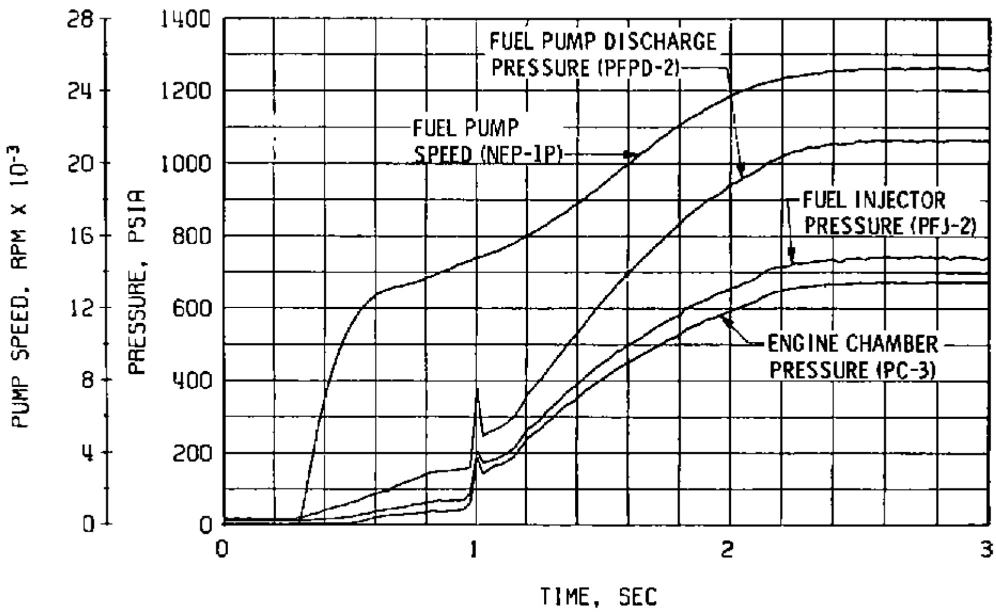


d. Crossover Duct, TFTD

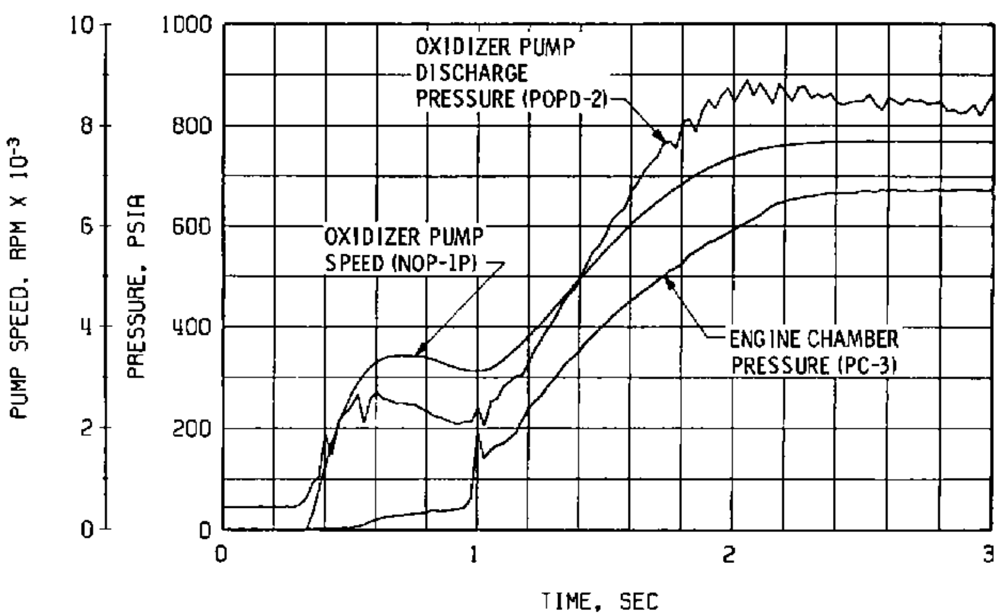


e. Thrust Chamber Throat, TTC-1P

Fig. 9 Concluded

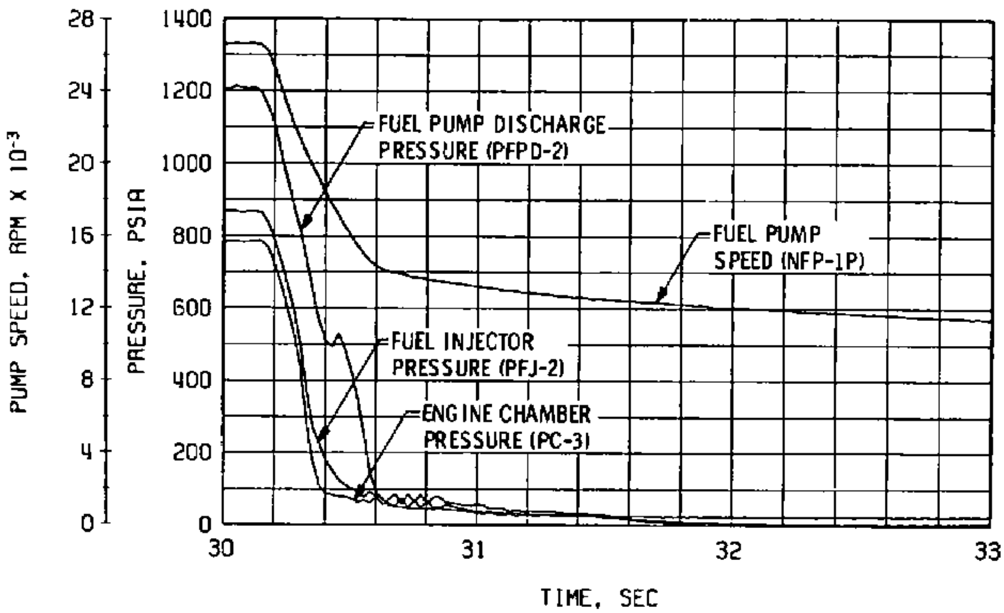


a. Start Transient Thrust Chamber Fuel System

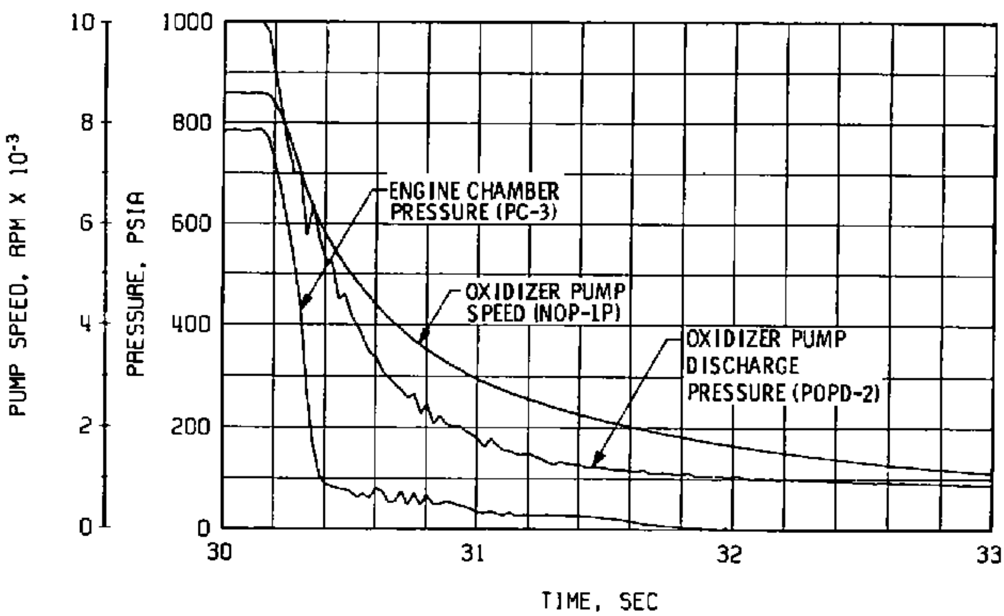


b. Start Transient Thrust Chamber Oxidizer System

Fig. 10 Engine Start and Shutdown Transients, Firing 02A

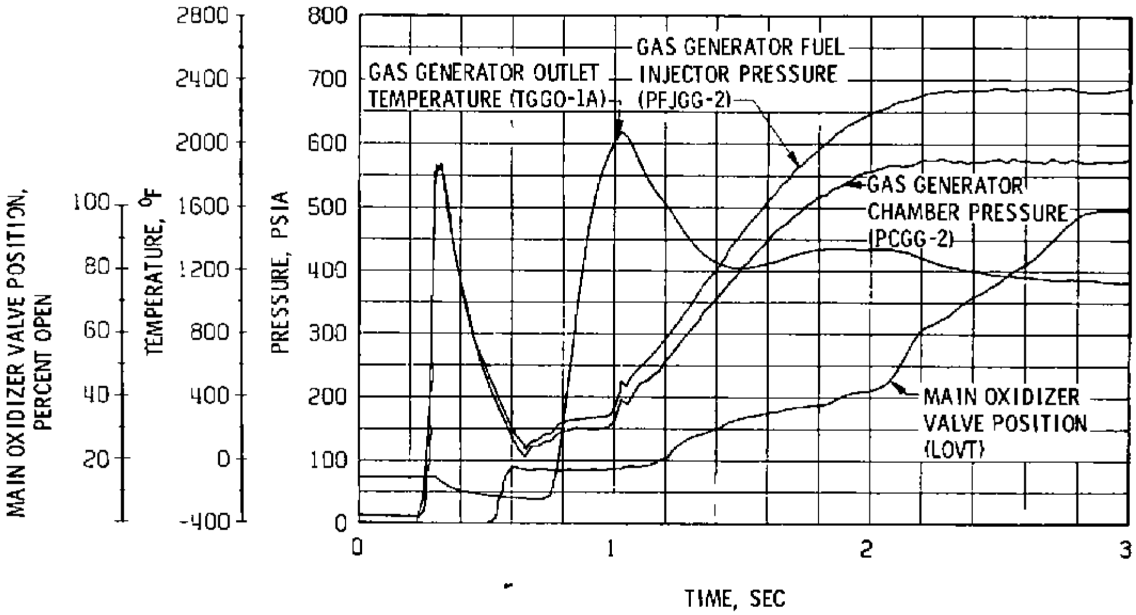


c. Shutdown Transient, Thrust Chamber Fuel System

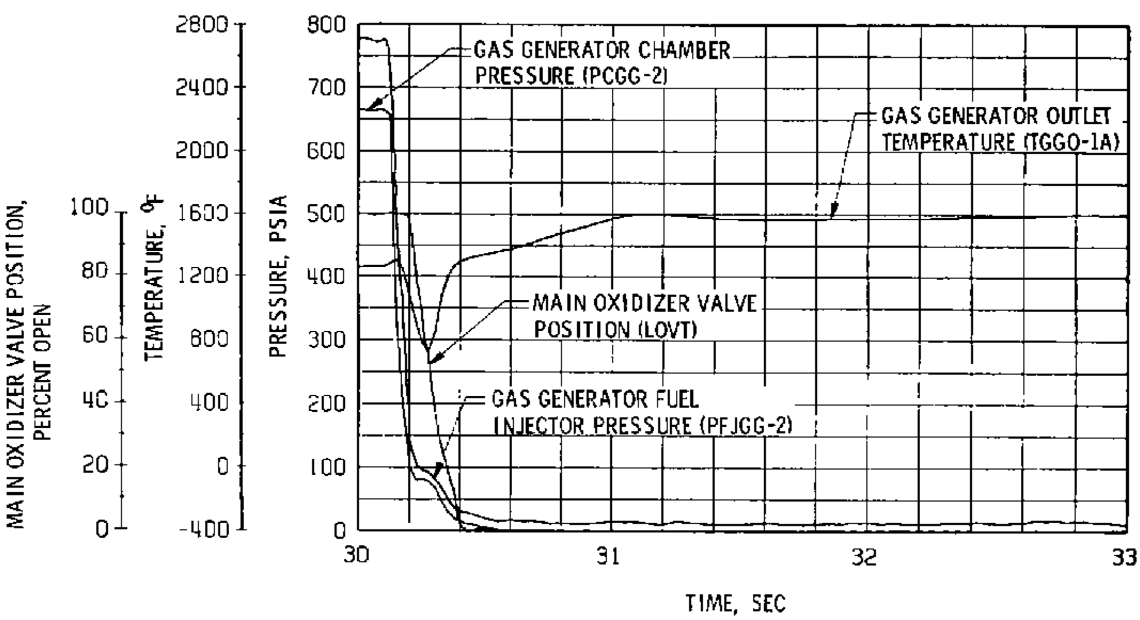


d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 10 Continued



e. Start Transient, Gas Generator System



f. Shutdown Transient Gas Generator System

Fig. 10 Concluded

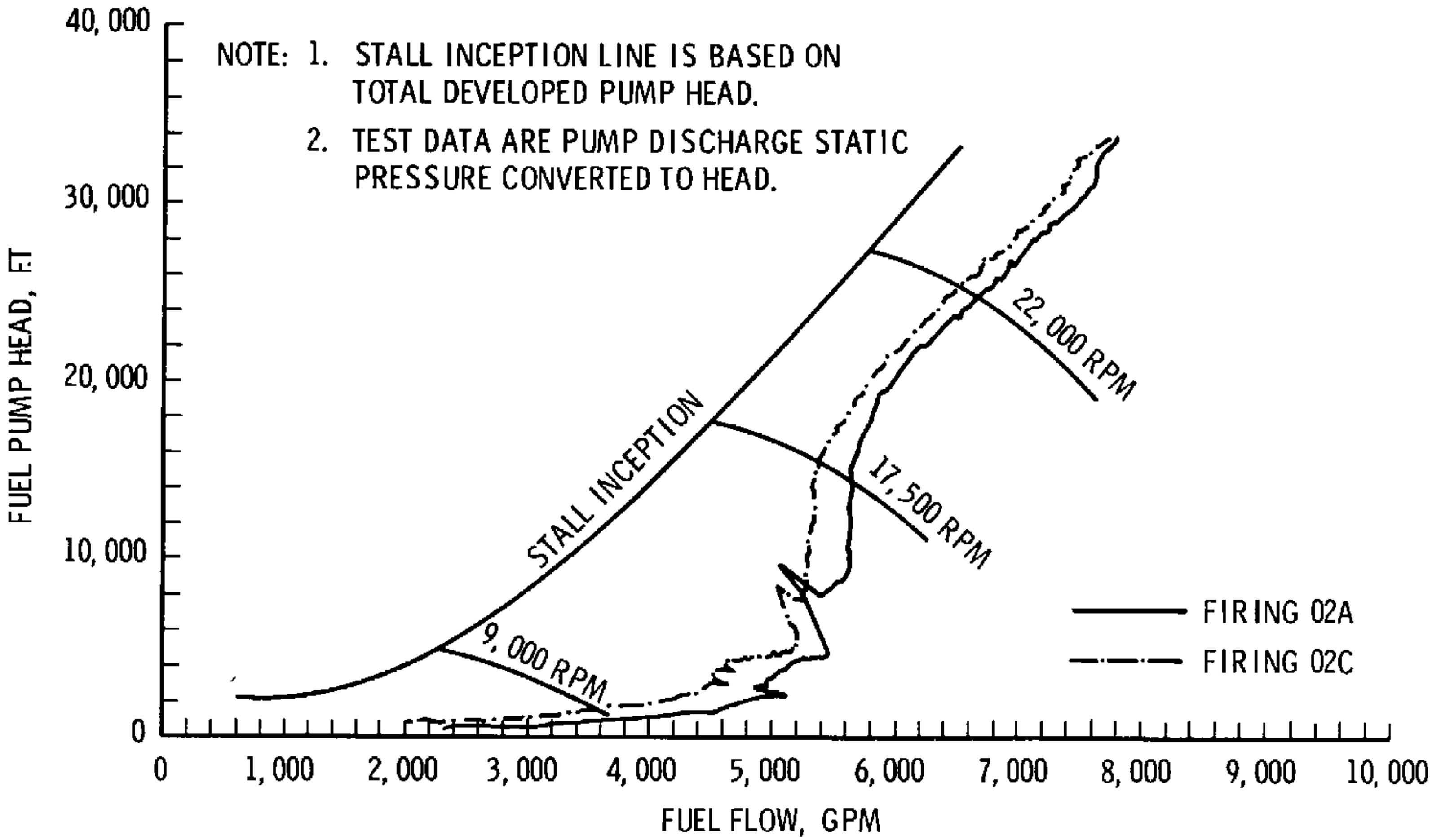


Fig. 11 Comparison of Fuel Pump Start Transient Performance, Firings 02A and 02C

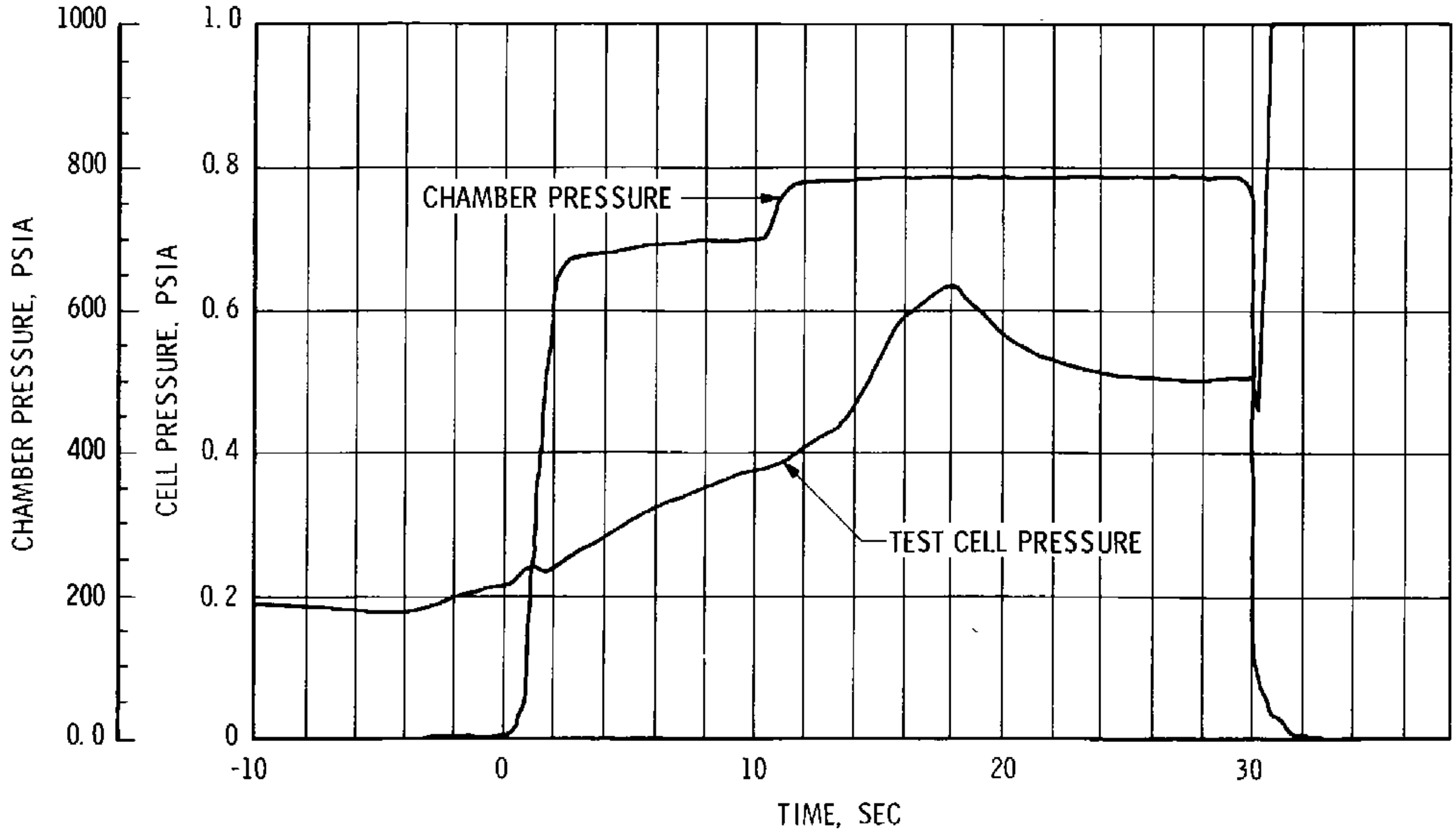


Fig. 12 Engine Chamber and Test Capsule Pressures, Firing 02A

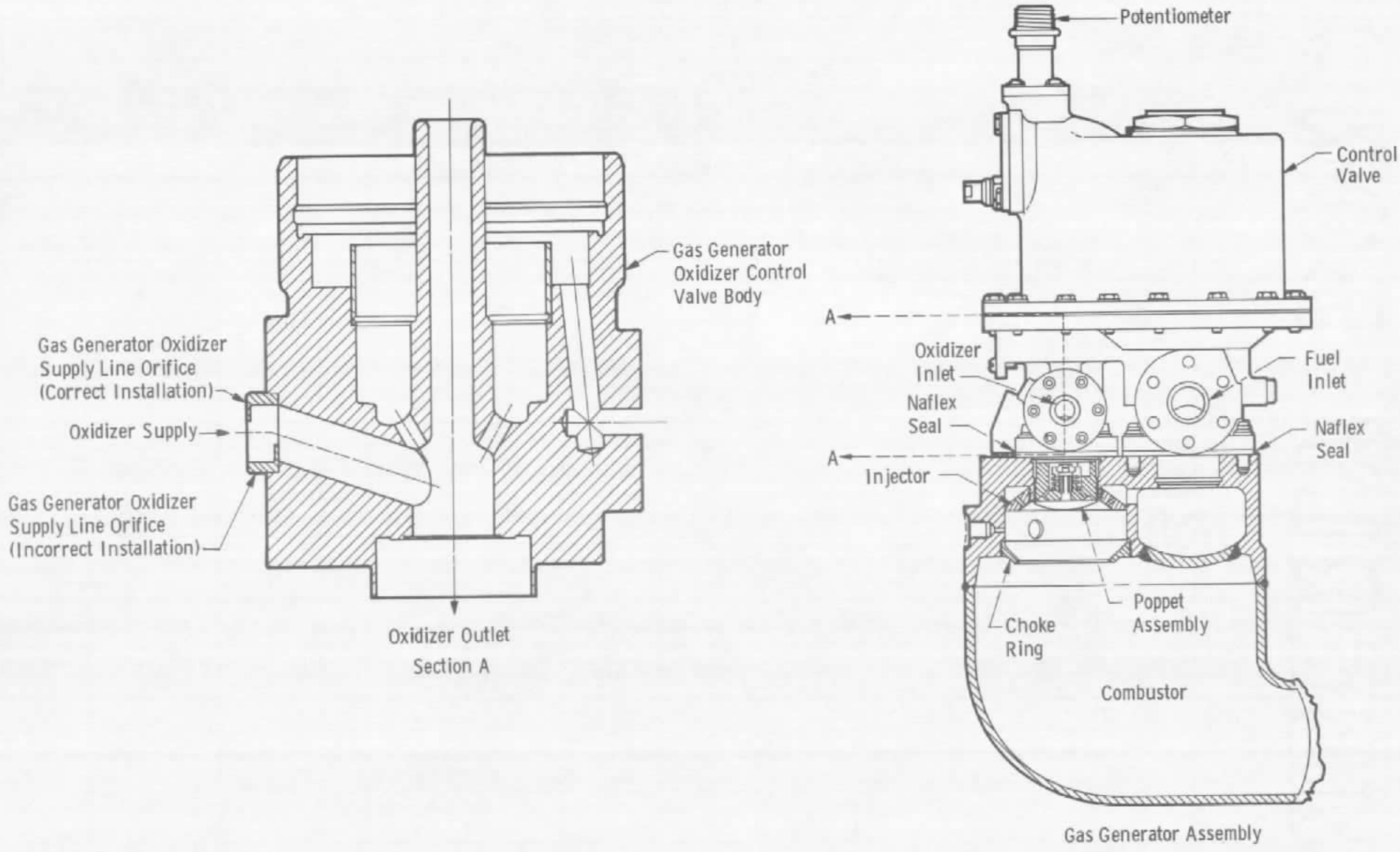
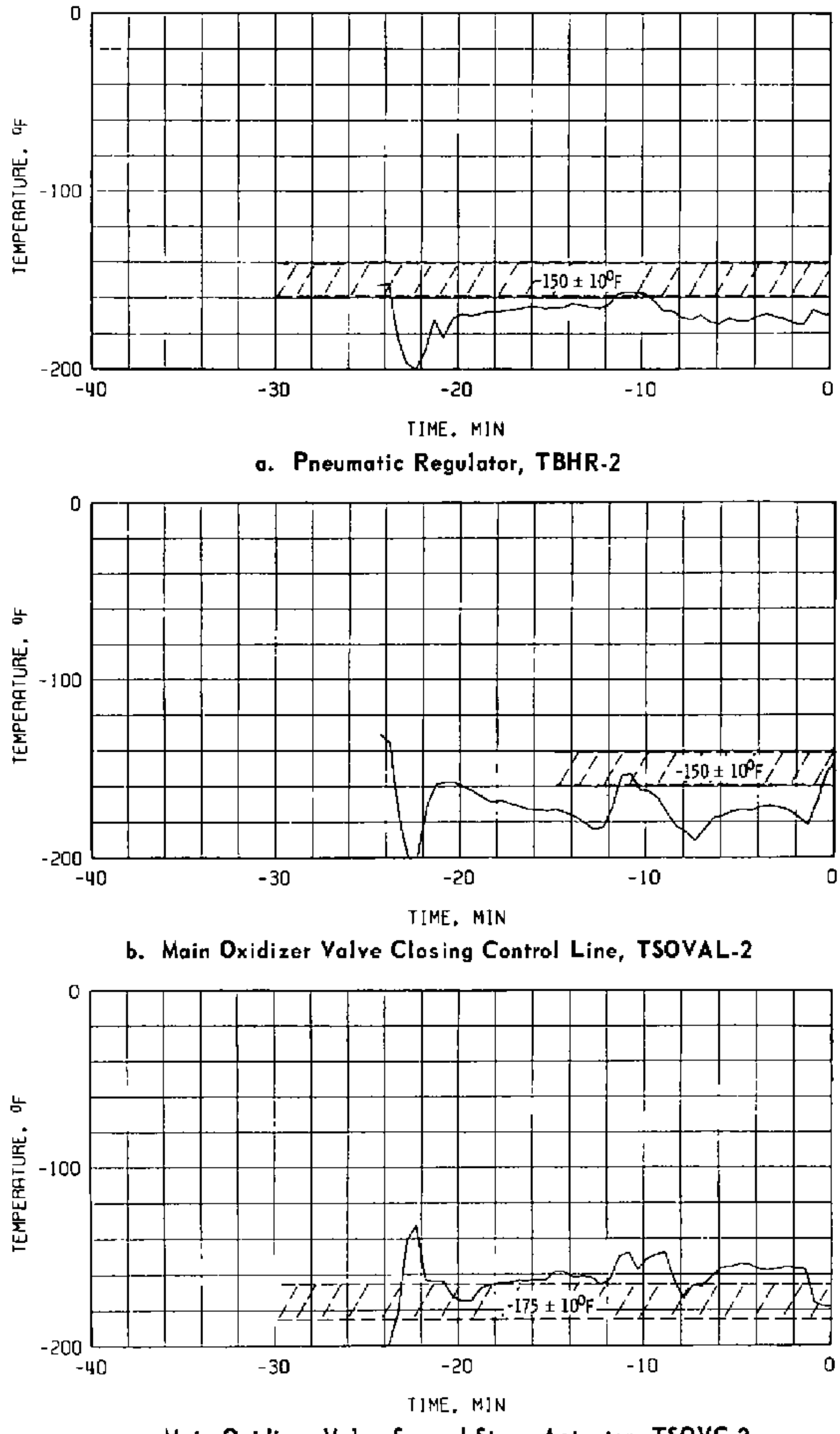


Fig. 13 Gas Generator Oxidizer Supply Line Orifice Installation

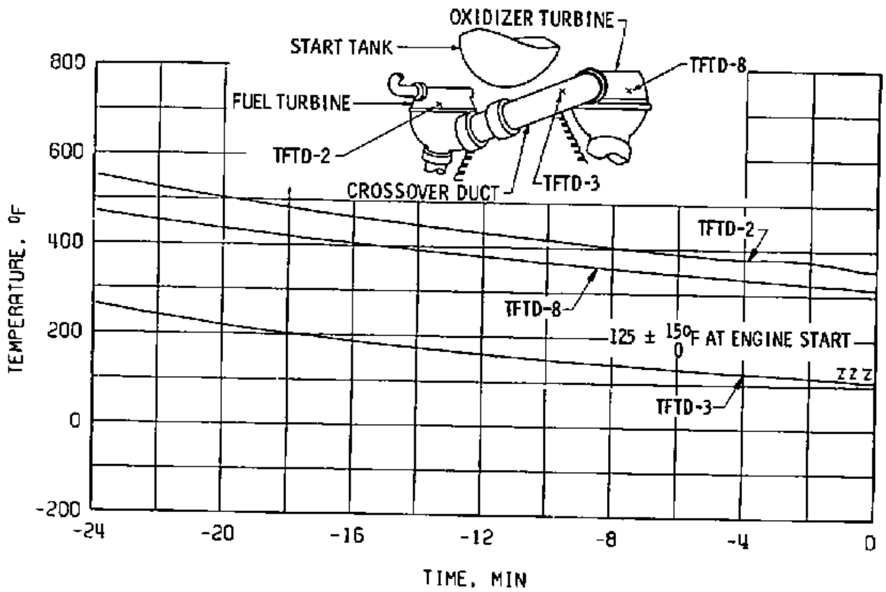


a. Pneumatic Regulator, TBHR-2

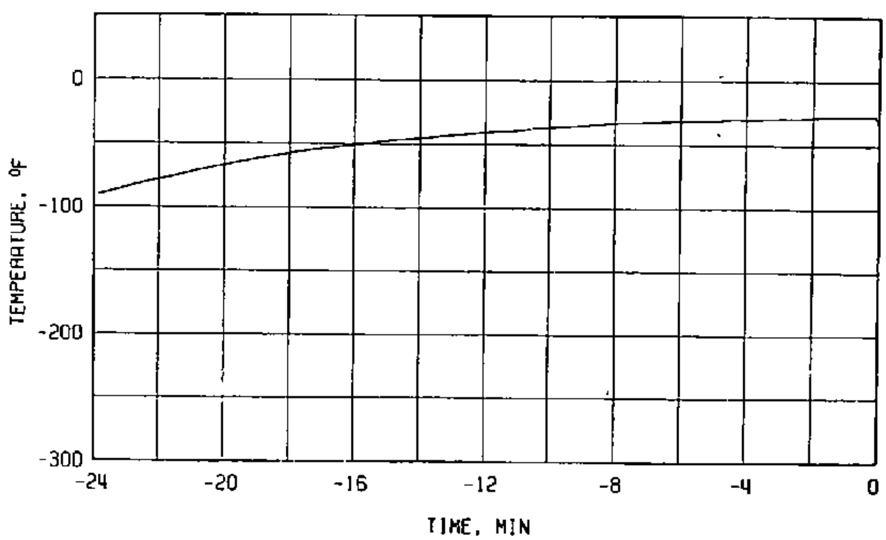
b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

c. Main Oxidizer Valve Second-Stage Actuator, TSOVC-2

Fig. 14 History of Firing 02B Pre-Fire Temperature Conditioning of Engine Components

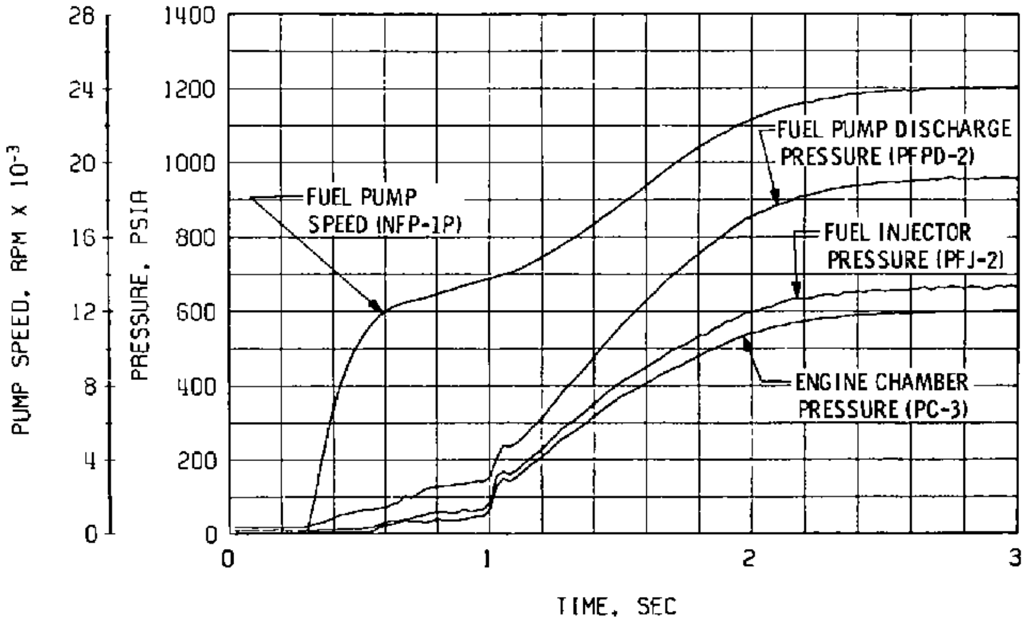


d. Crossover Duct, TFTD

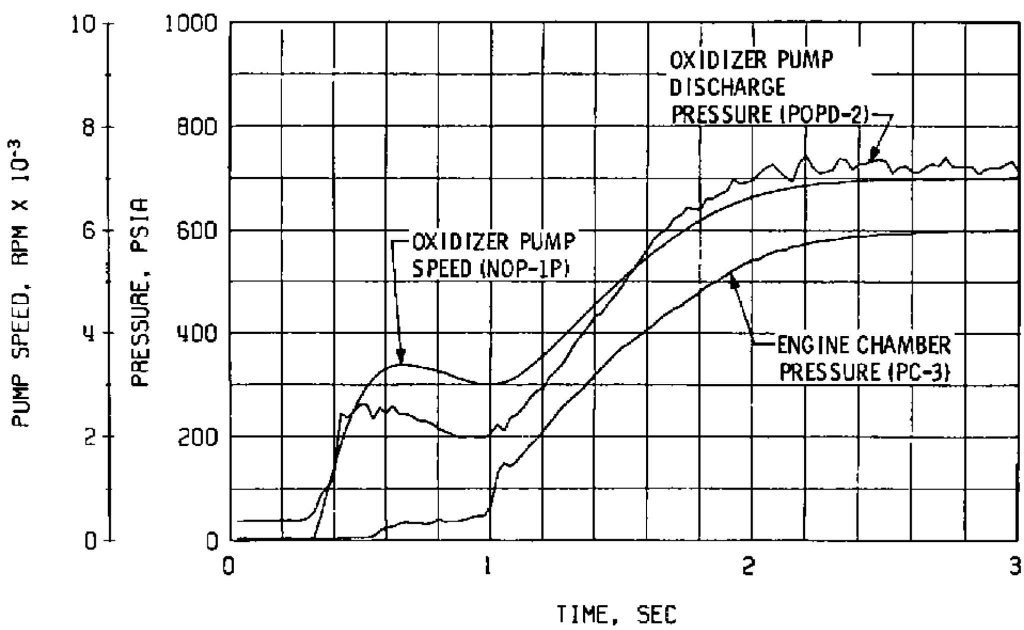


e. Thrust Chamber Throat, TTC-1P

Fig. 14 Concluded

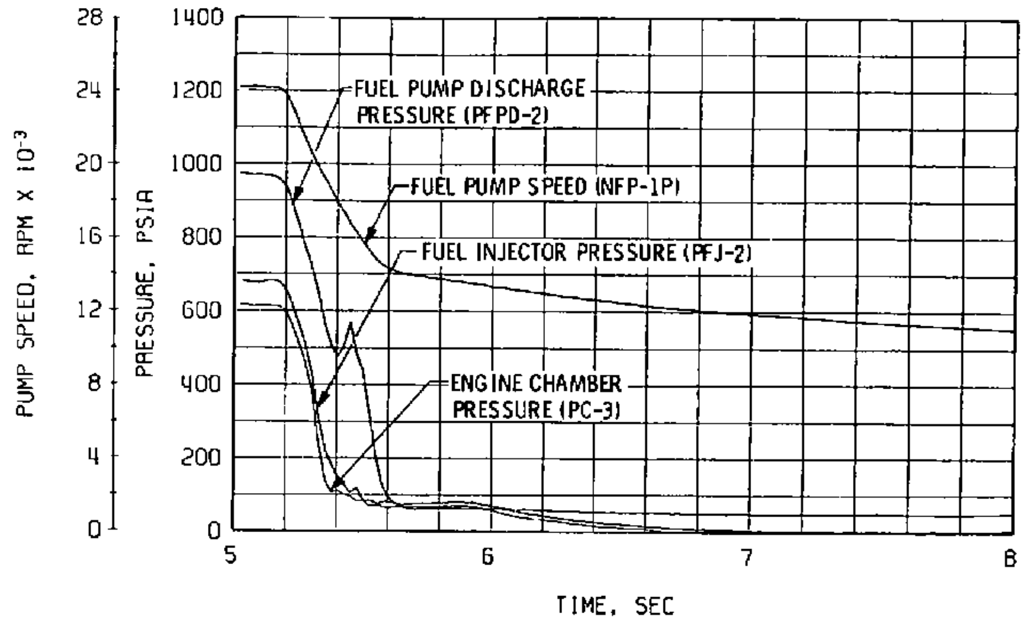


a. Start Transient, Thrust Chamber Fuel System

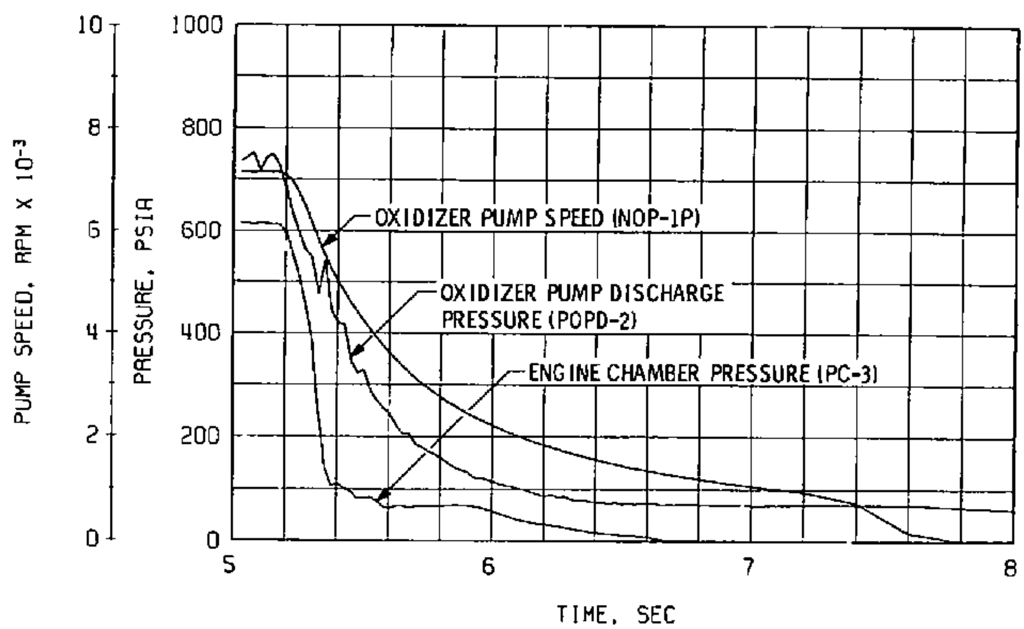


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 15 Engine Start and Shutdown Transients, Firing 02B

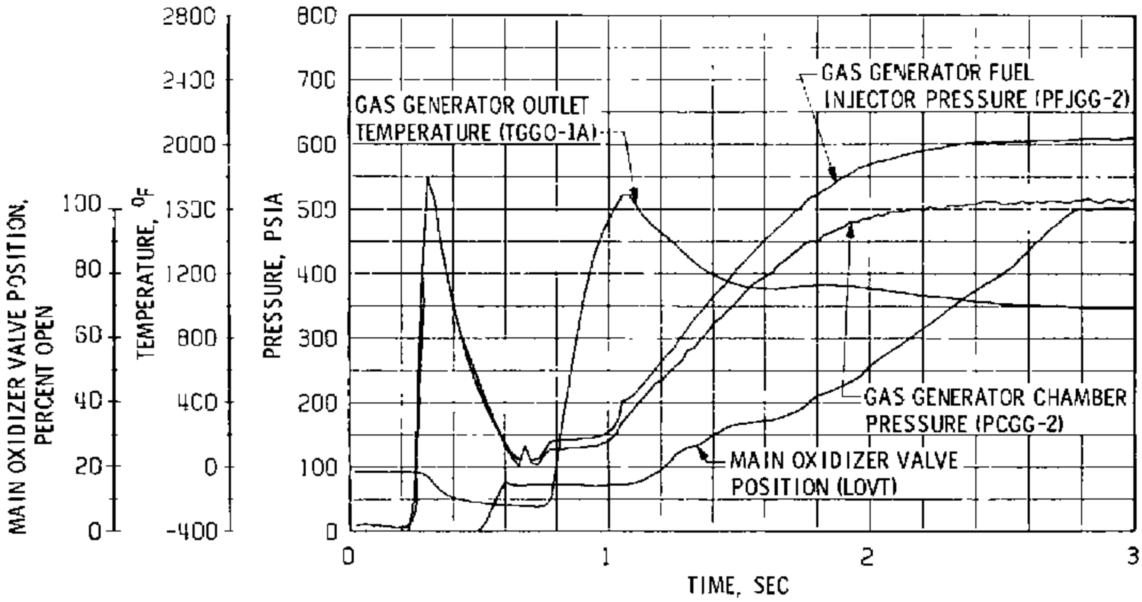


c. Shutdown Transient, Thrust Chamber Fuel System

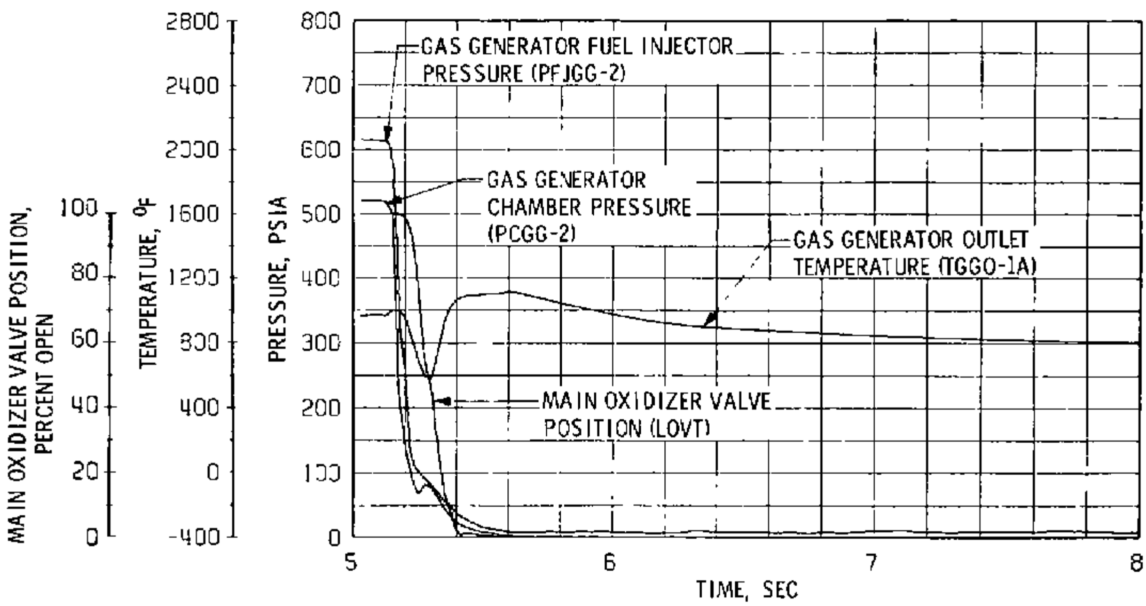


d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 15 Continued



e. Start Transient, Gas Generator System



f. Shutdown Transient, Gas Generator System

Fig. 15 Concluded

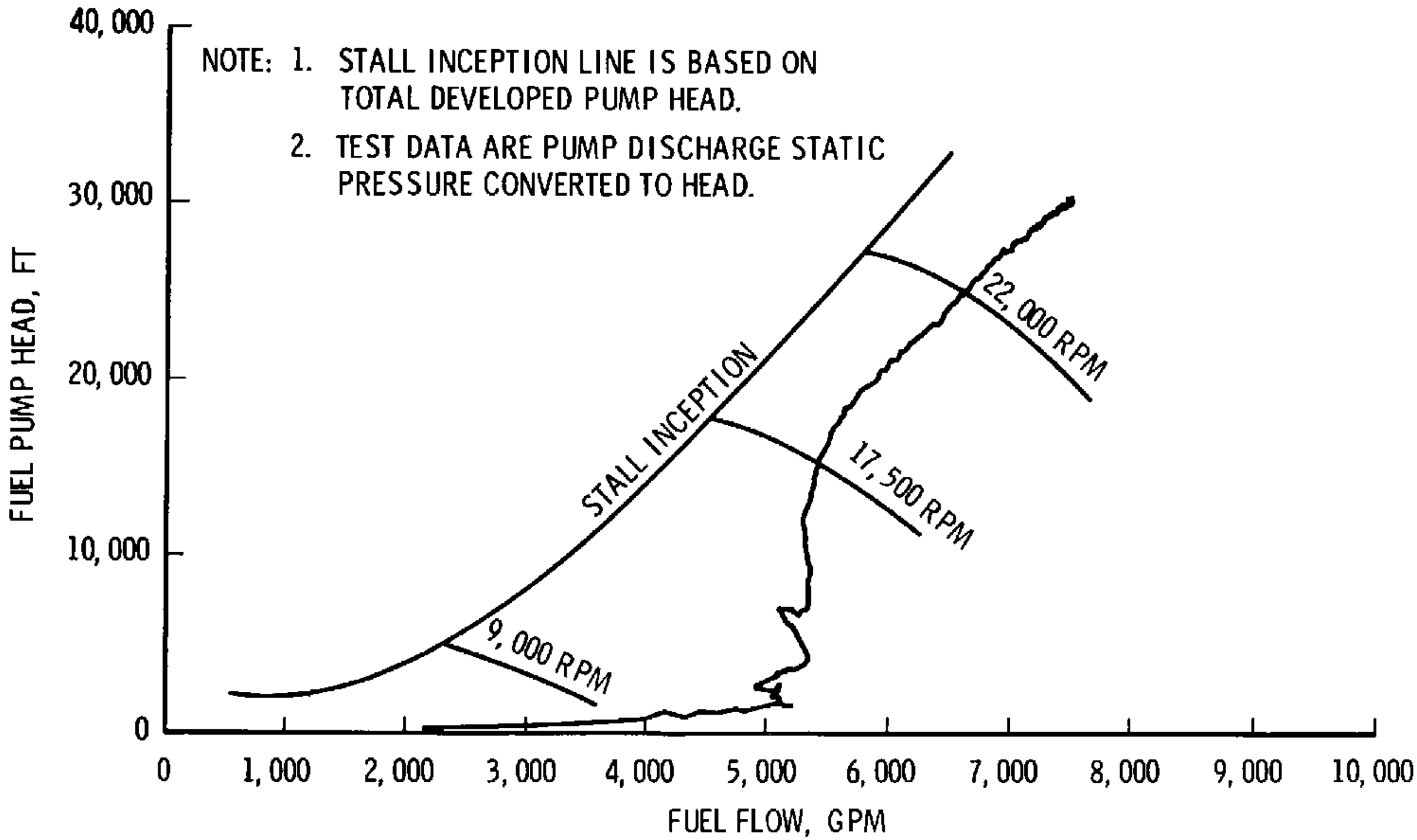


Fig. 16 Fuel Pump Start Transient Performance, Firing 02B

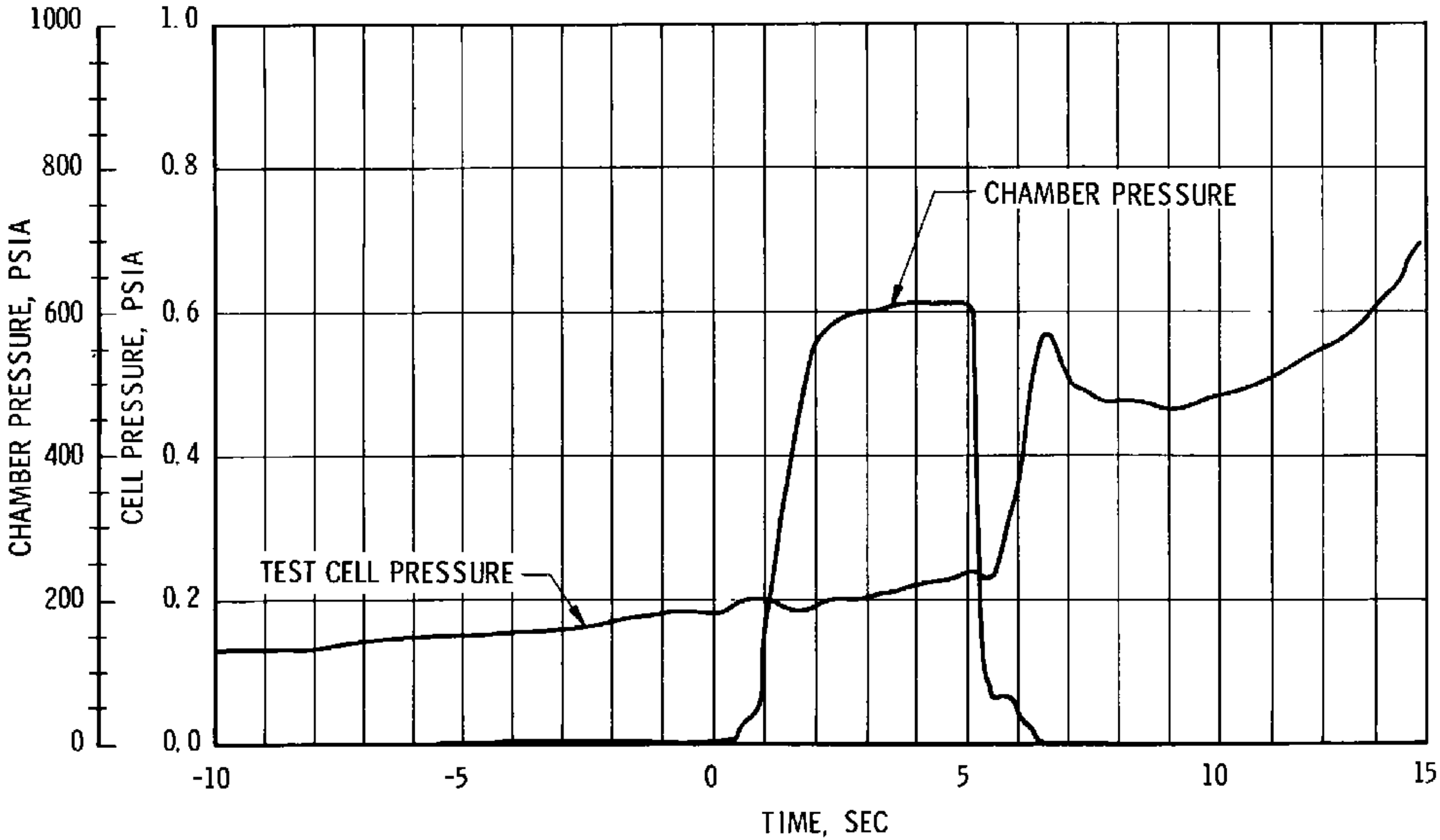
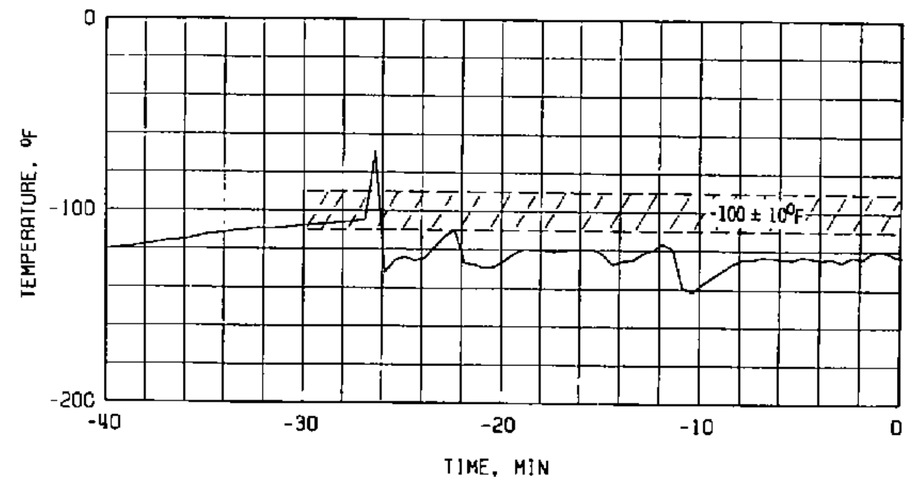
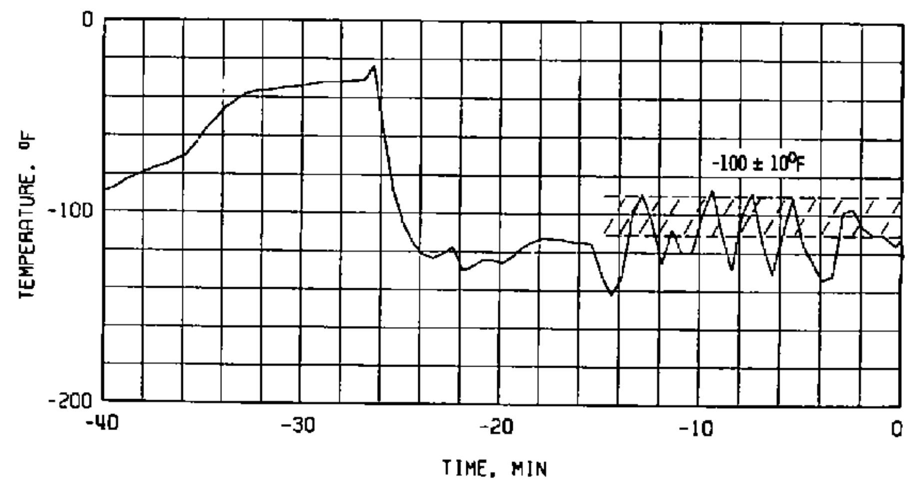


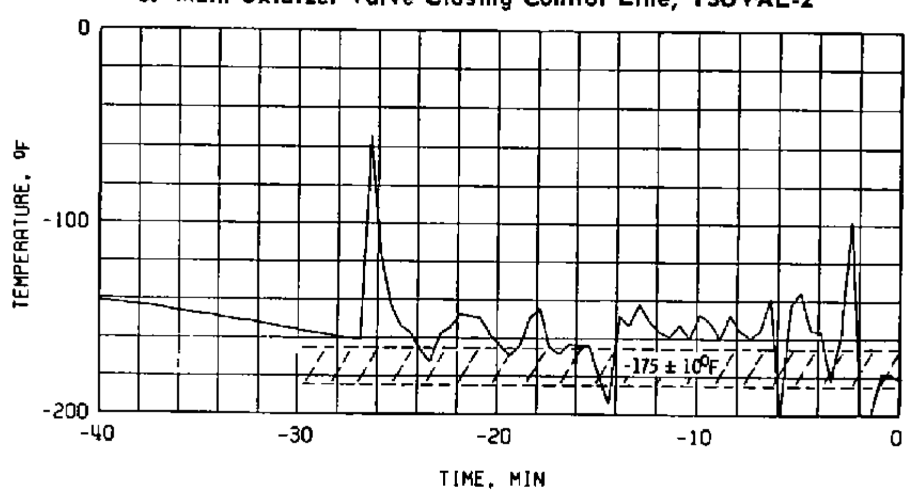
Fig. 17 Engine Chamber and Test Capsule Pressure, Firing 02B



a. Pneumatic Regulator, TBHR-2

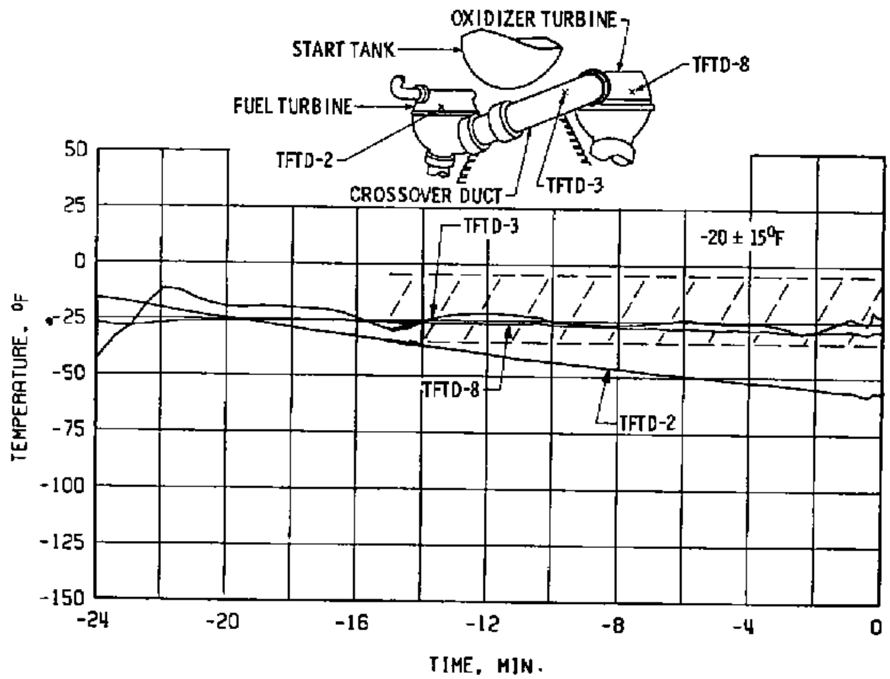


b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

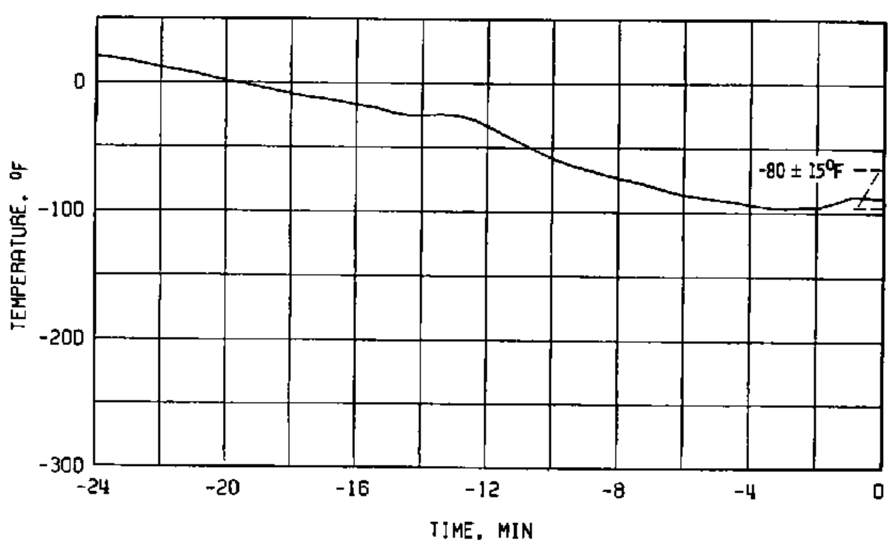


c. Main Oxidizer Valve Second-Stage Actuator, TSOVC-2

Fig. 18 History of Firing 02C Pre-Fire Temperature Conditioning

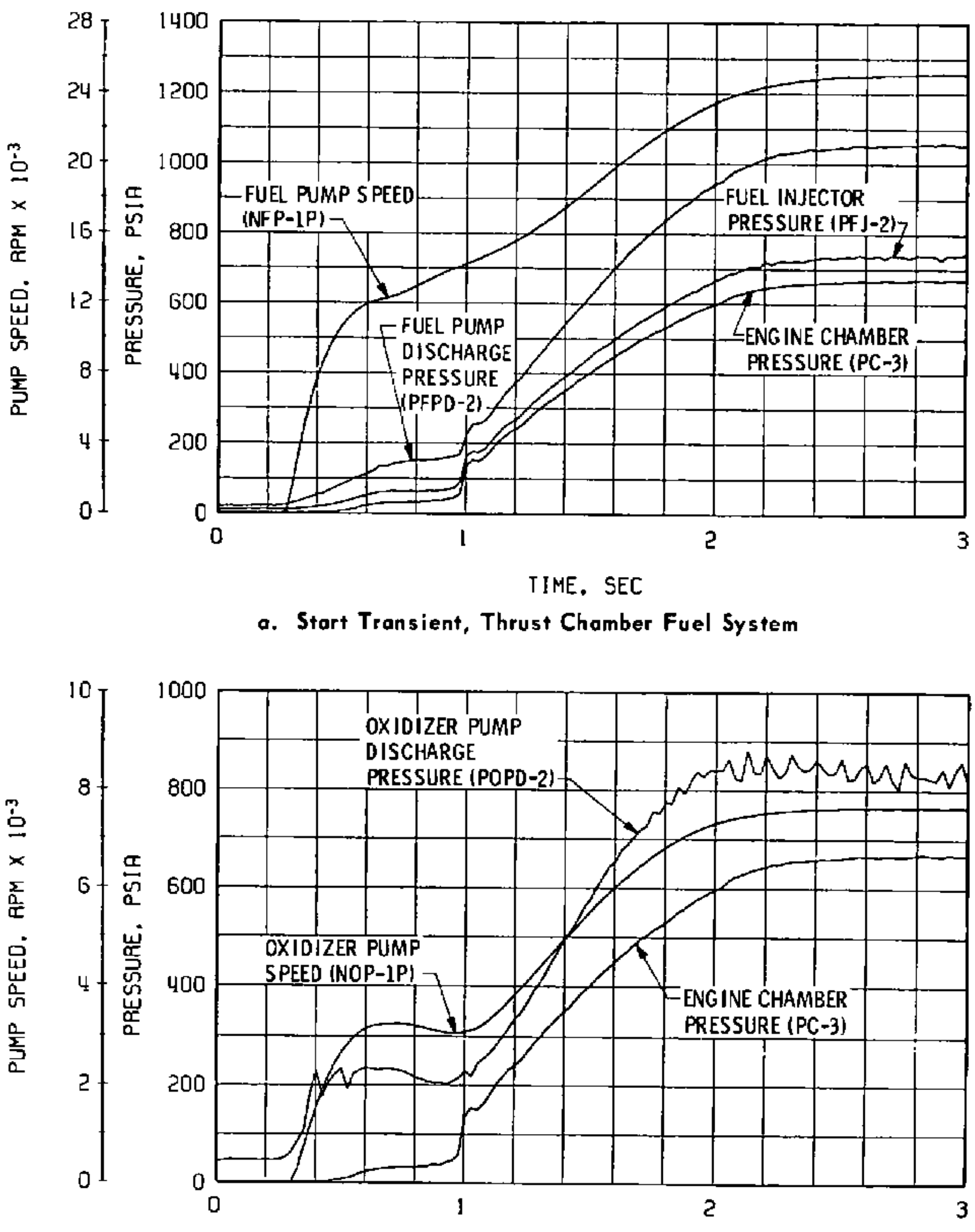


d. Crossover Duct, TFTD



e. Thrust Chamber Throat, TTC-1P

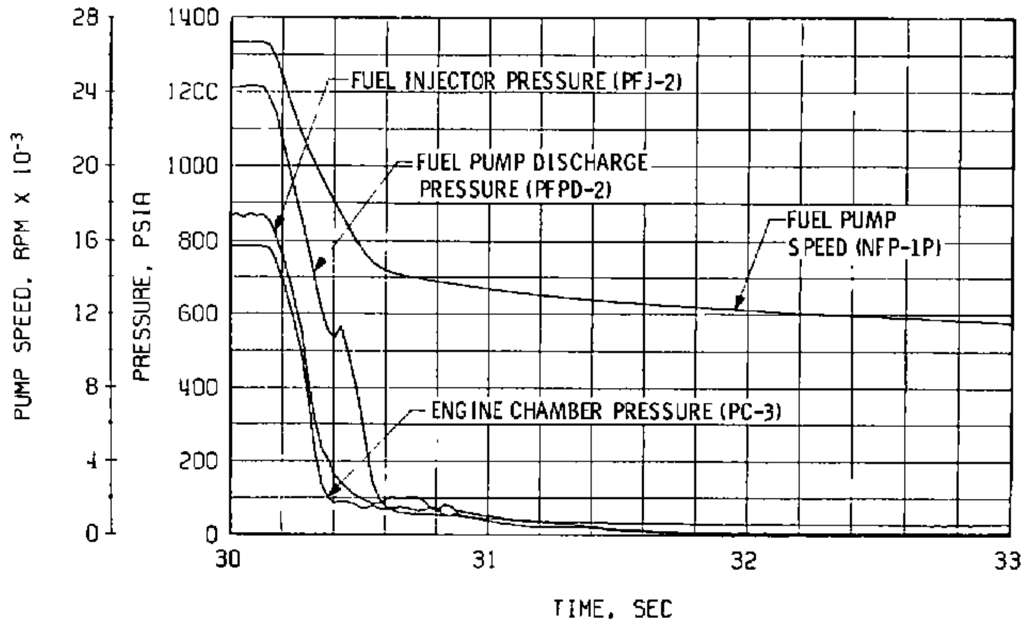
Fig. 18 Concluded



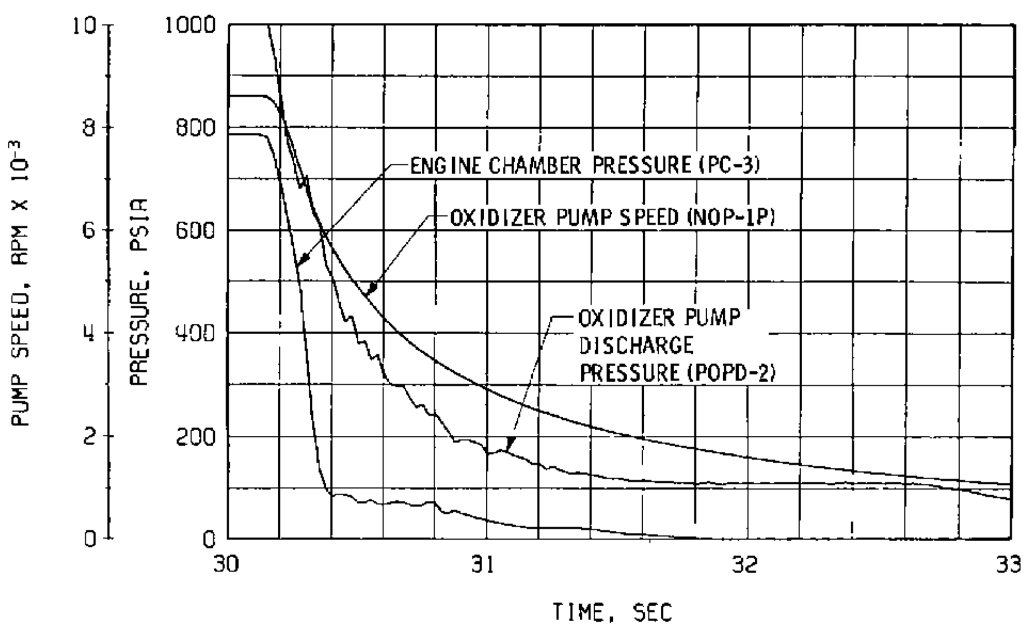
a. Start Transient, Thrust Chamber Fuel System

b. Start Transient, Thrust Chamber Oxidizer System

Fig. 19 Engine Start and Shutdown Transients, Firing 02C

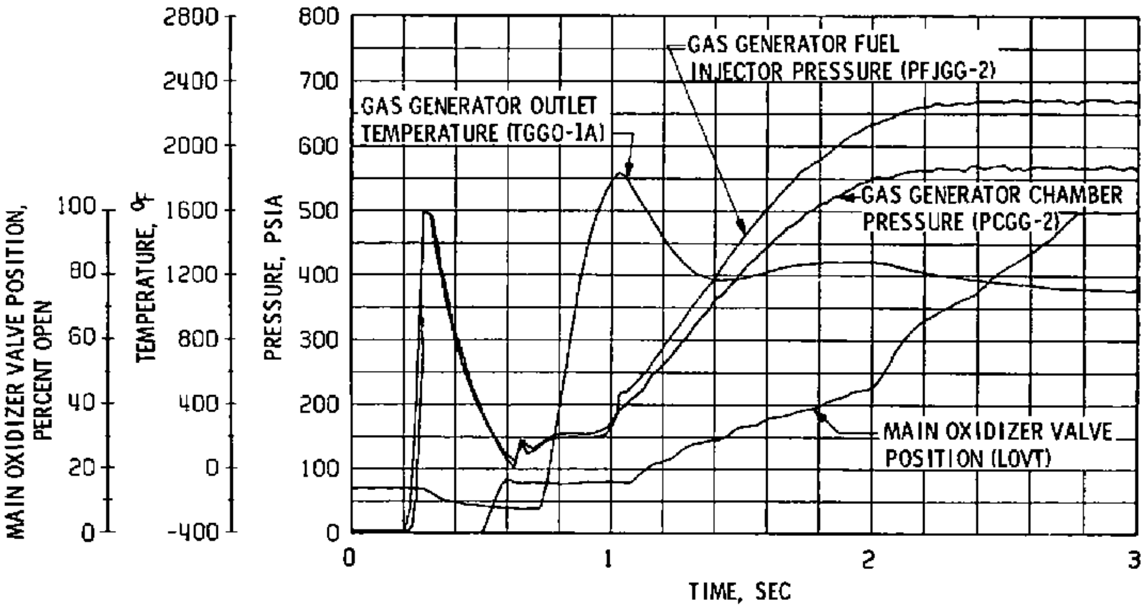


c. Shutdown Transient, Thrust Chamber Fuel System

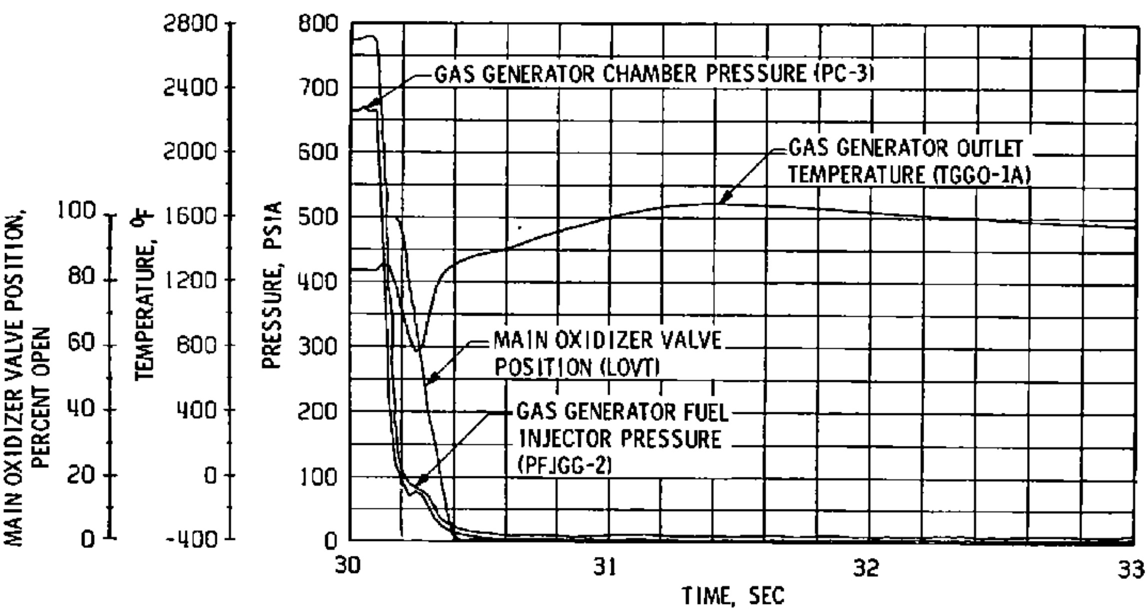


d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 19 Continued



e. Start Transient, Gas Generator System



f. Shutdown Transient, Gas Generator System

Fig. 19 Concluded

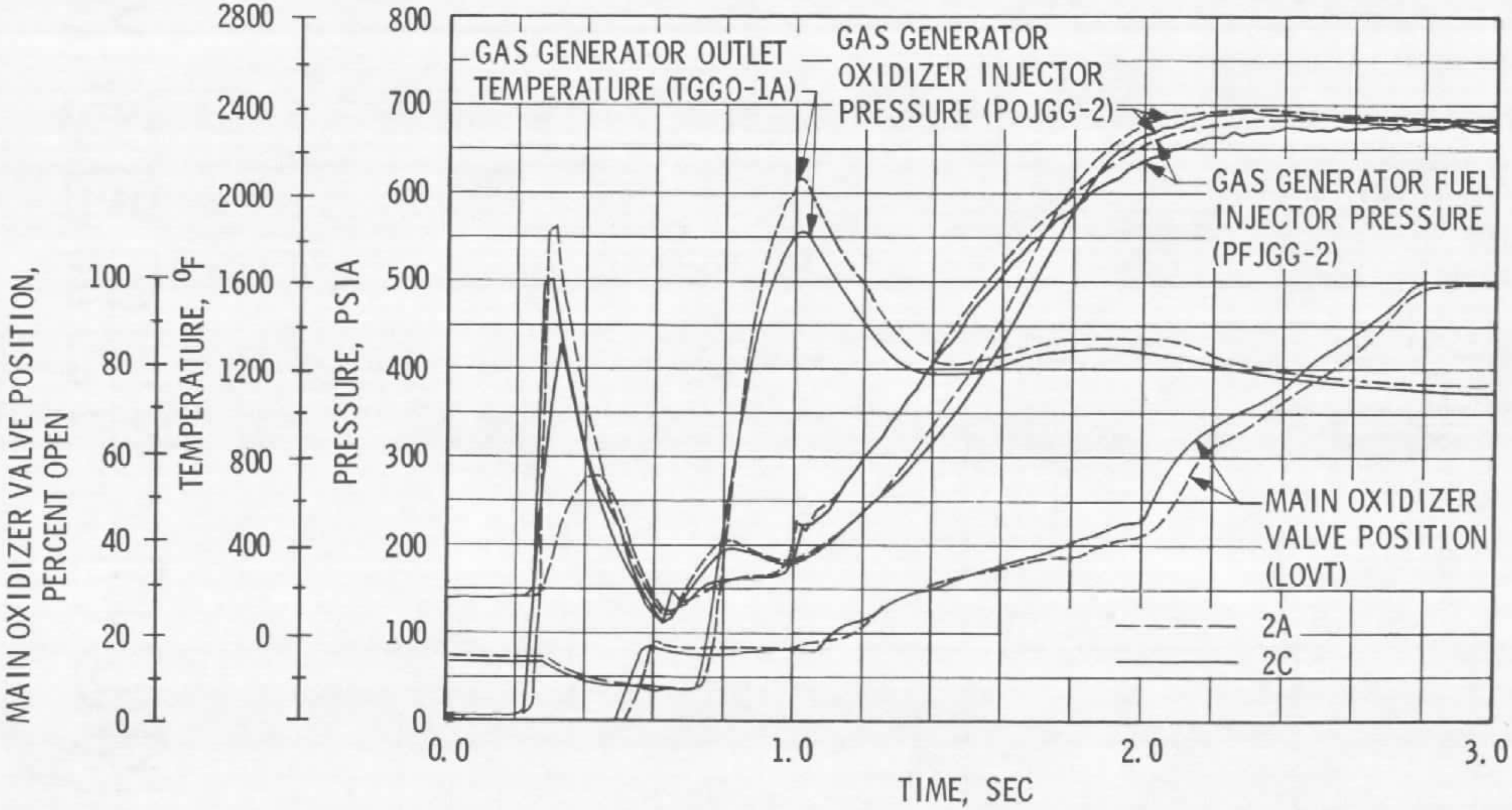


Fig. 20 Comparison of Gas Generator Start Transient for Firings 02A and 02C

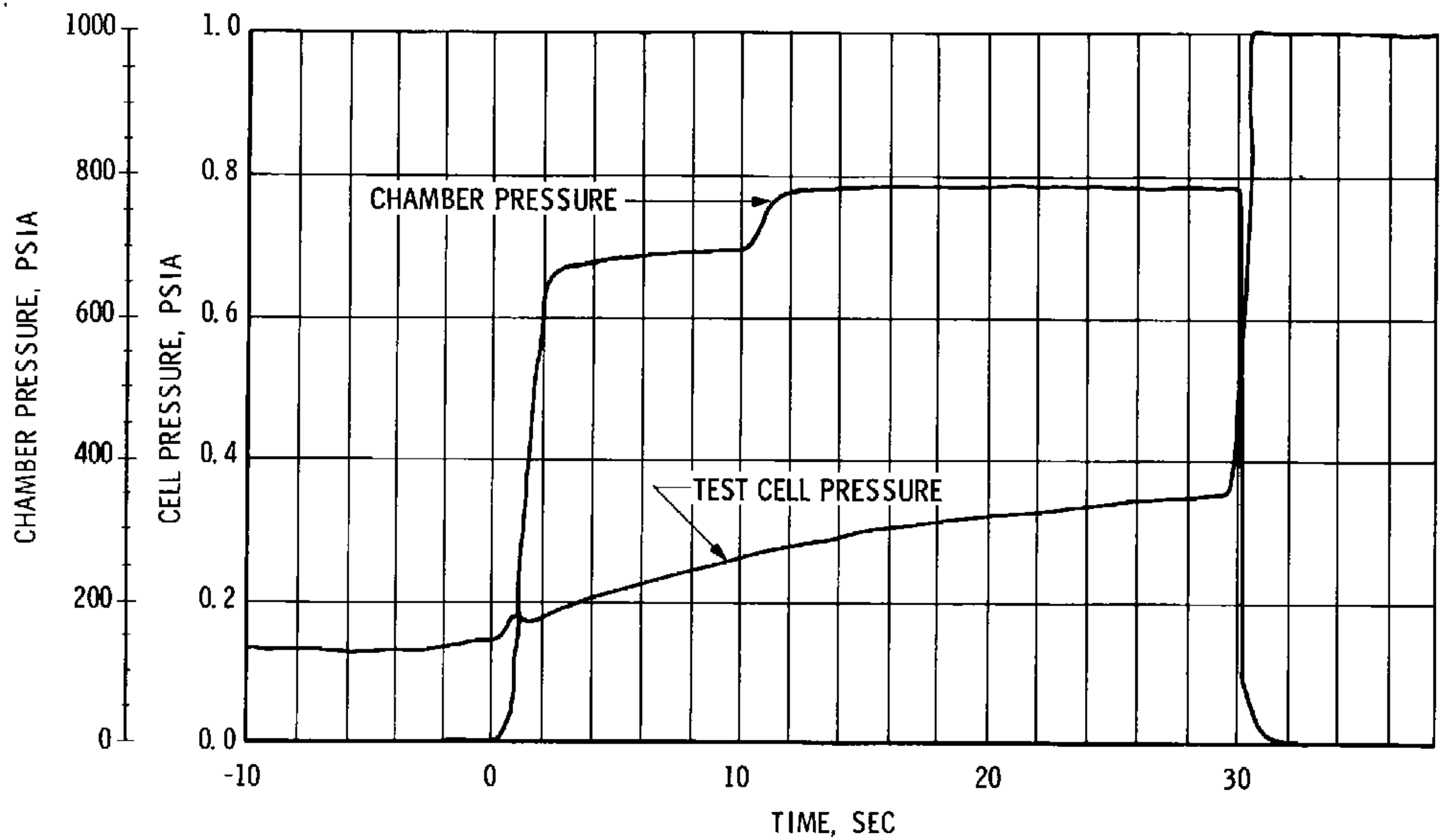
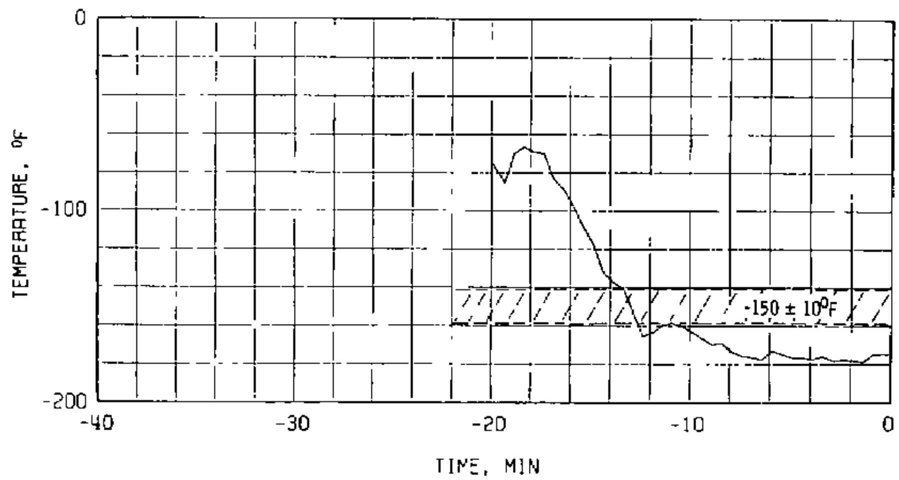
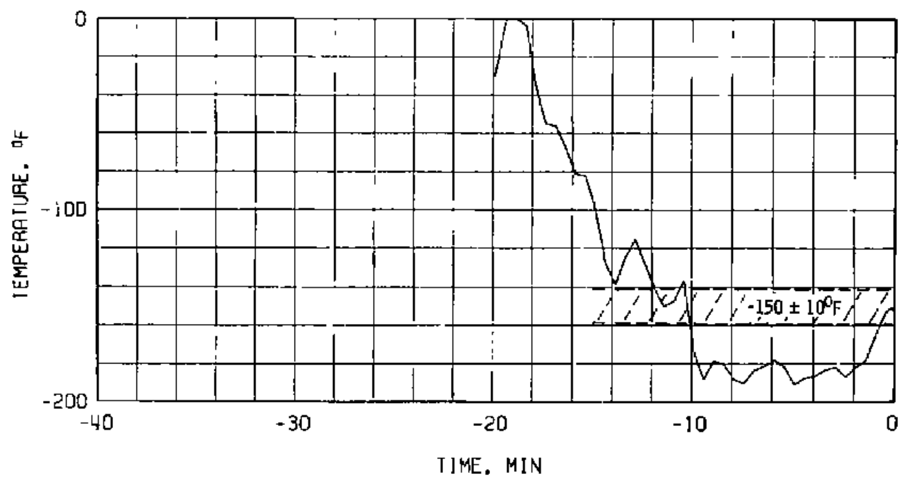


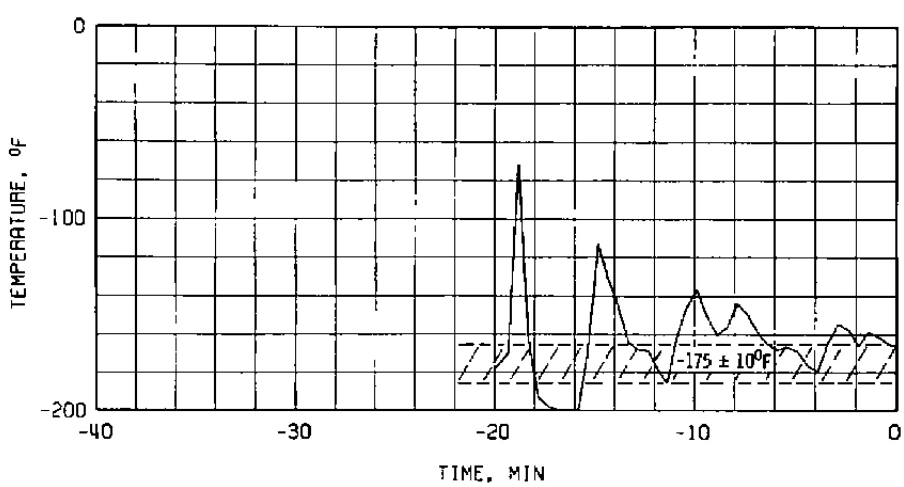
Fig. 21 Engine Chamber and Test Capsule Pressures, Firing 02C



a. Pneumatic Regulator, TBHR-2

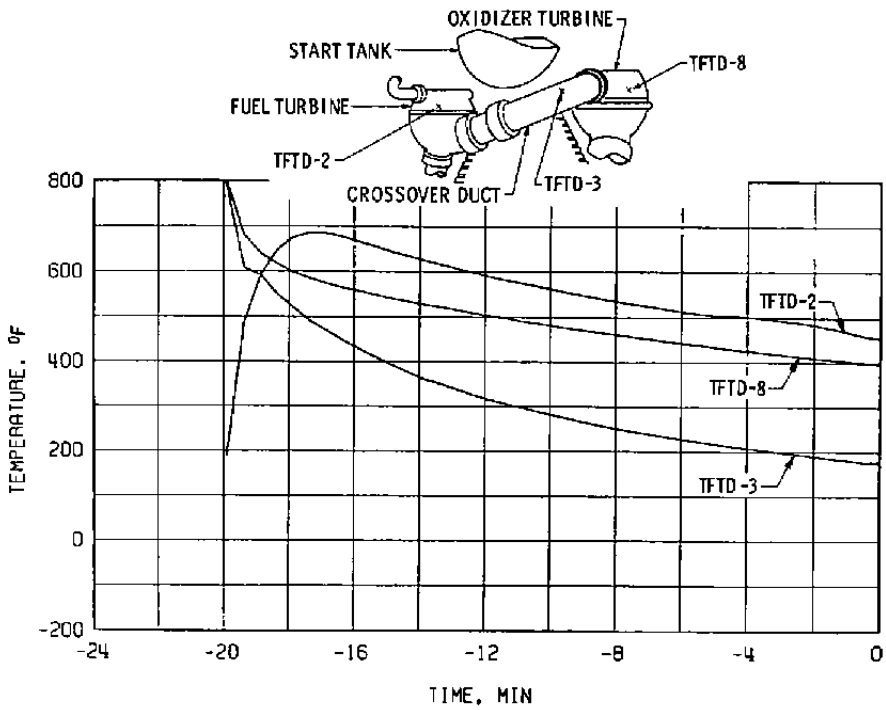


b. Main Oxidizer Valve Closing Control Line, TSOVAL-2

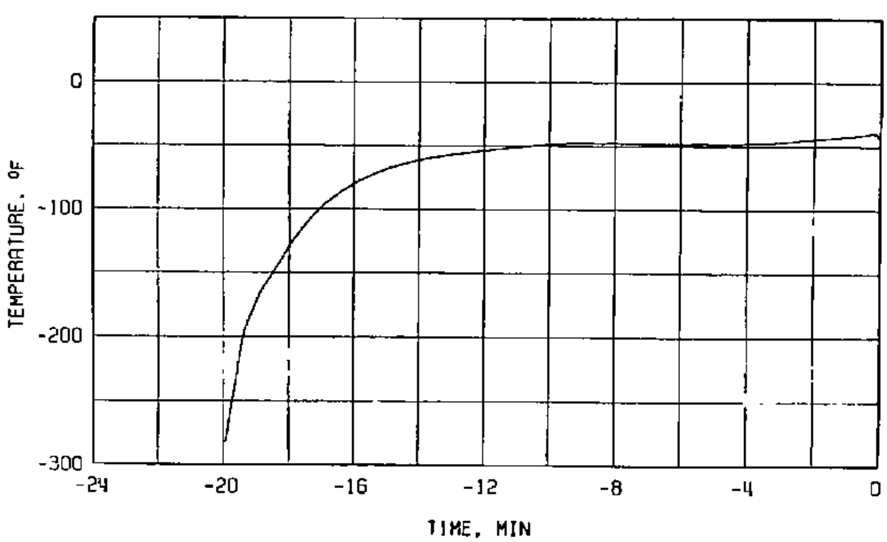


c. Main Oxidizer Valve Second-Stage Actuator, TSOVAL-2

Fig. 22 History of Firing 02D Pre-Fire Temperature Conditioning of Engine Components

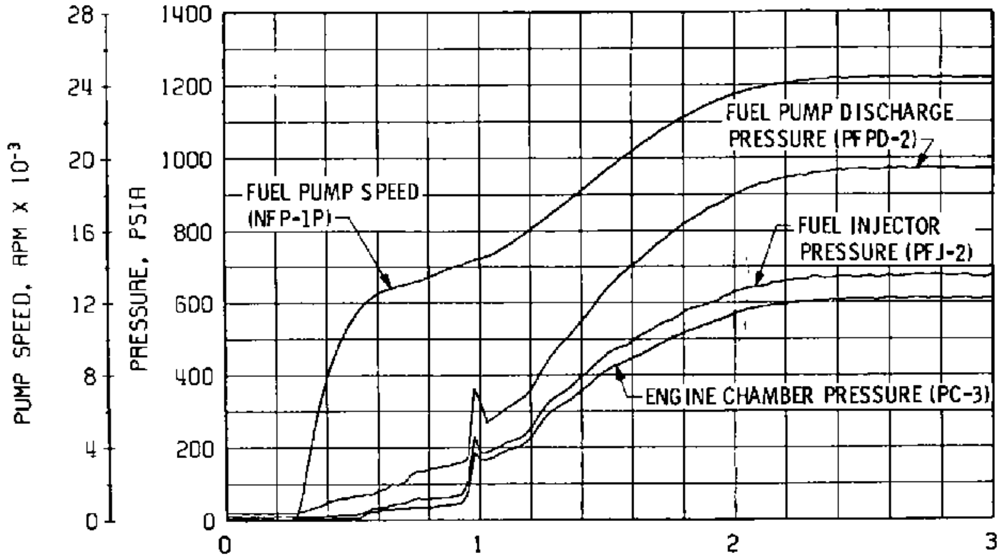


d. Crossover Duct, TFTD

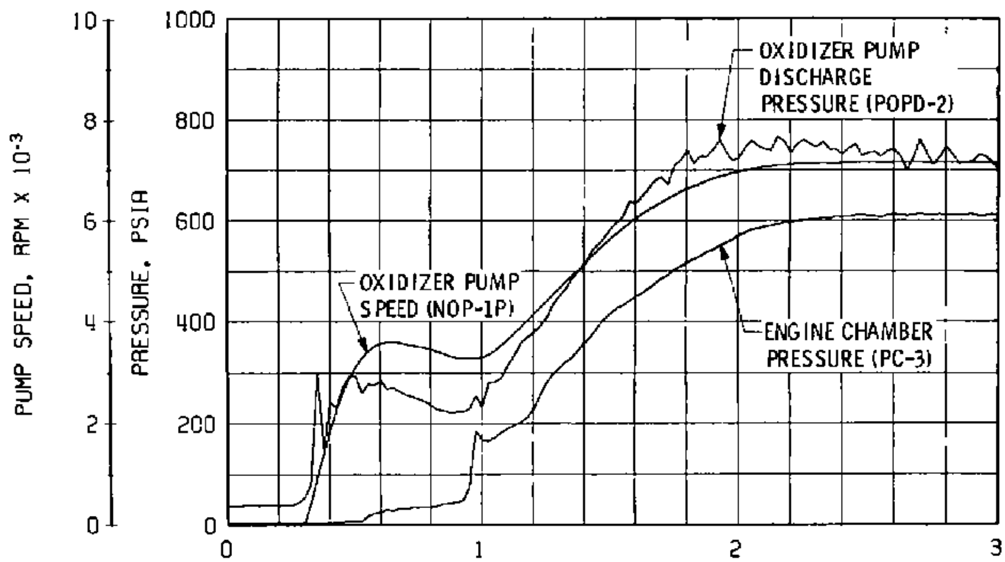


e. Thrust Chamber Throat, TTC-1P

Fig. 22 Concluded

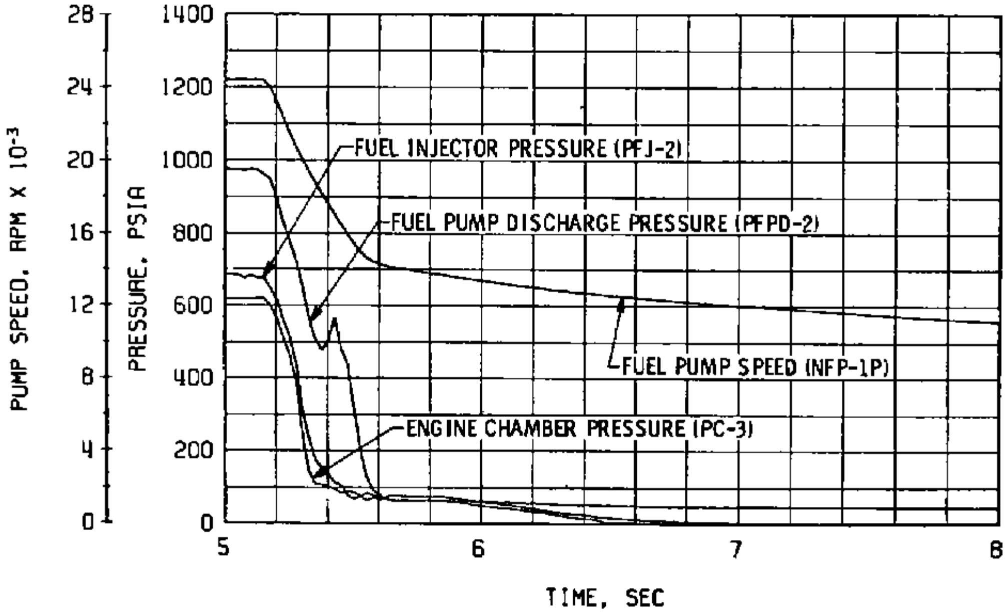


a. Start Transient, Thrust Chamber Fuel System

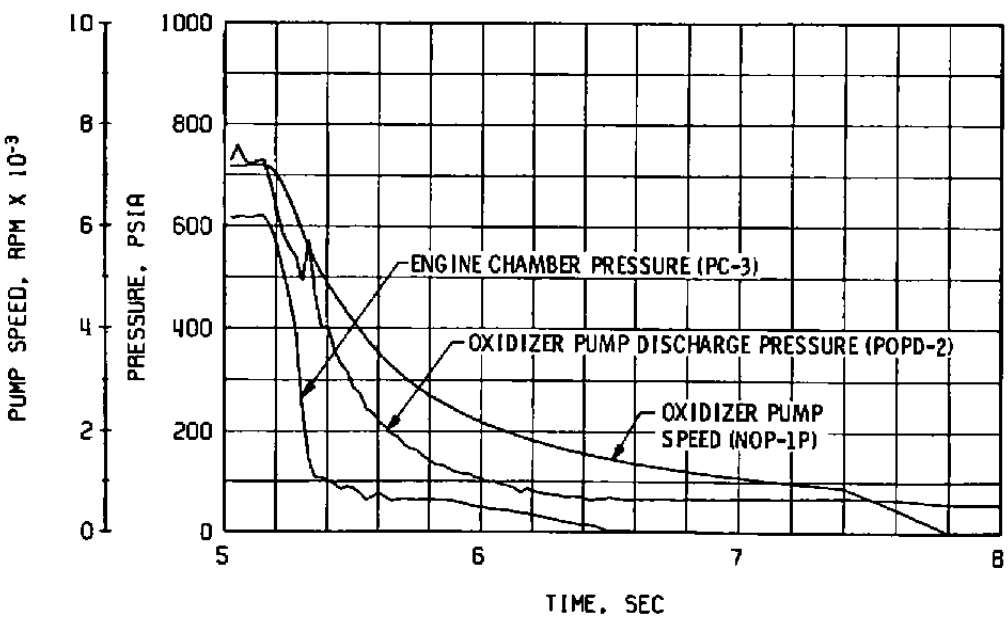


b. Start Transient, Thrust Chamber Oxidizer System

Fig. 23 Engine Start and Shutdown Transients, Firing 02D

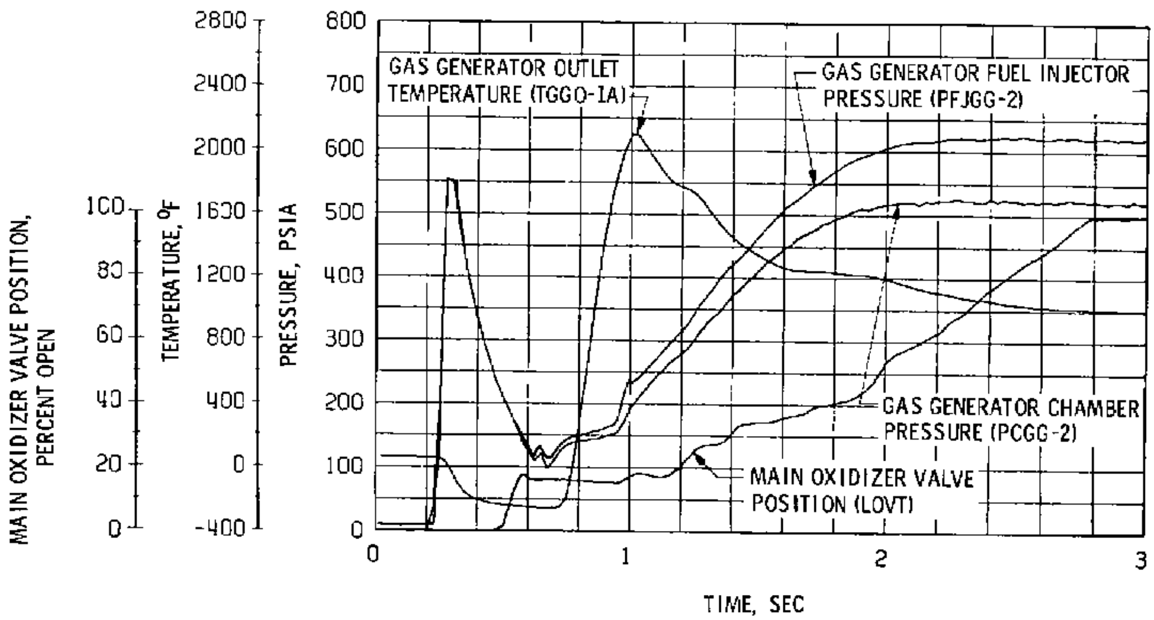


c. Shutdown Transient, Thrust Chamber Fuel System

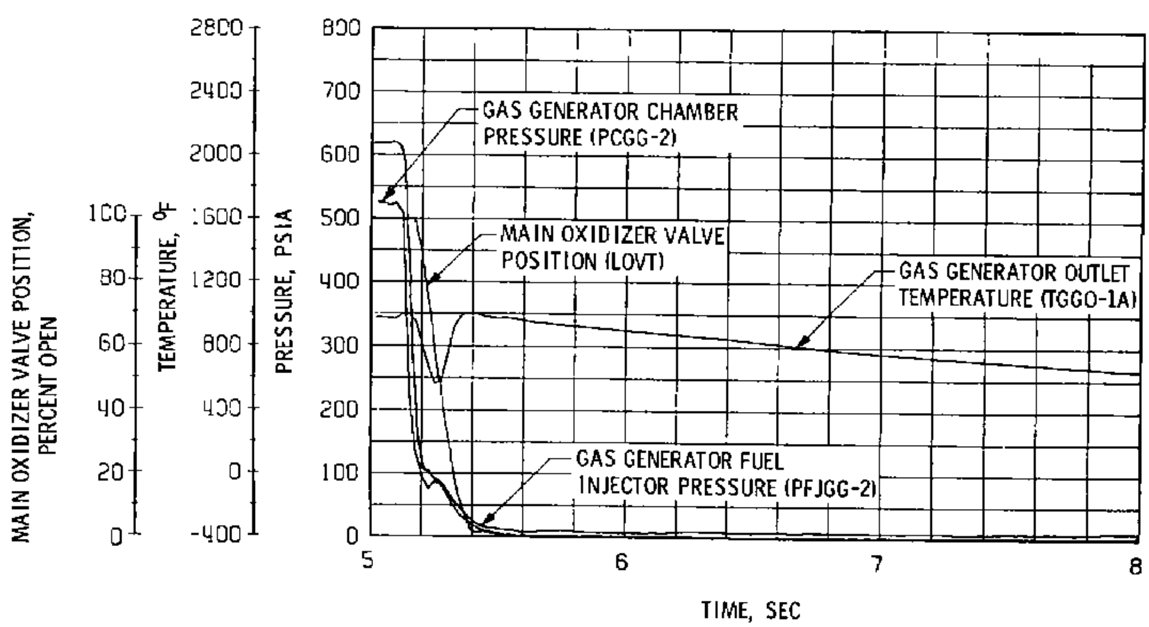


d. Shutdown Transient, Thrust Chamber Oxidizer System

Fig. 23 Continued



e. Start Transient, Gas Generator System



f. Shutdown Transient, Gas Generator System

Fig. 23 Concluded

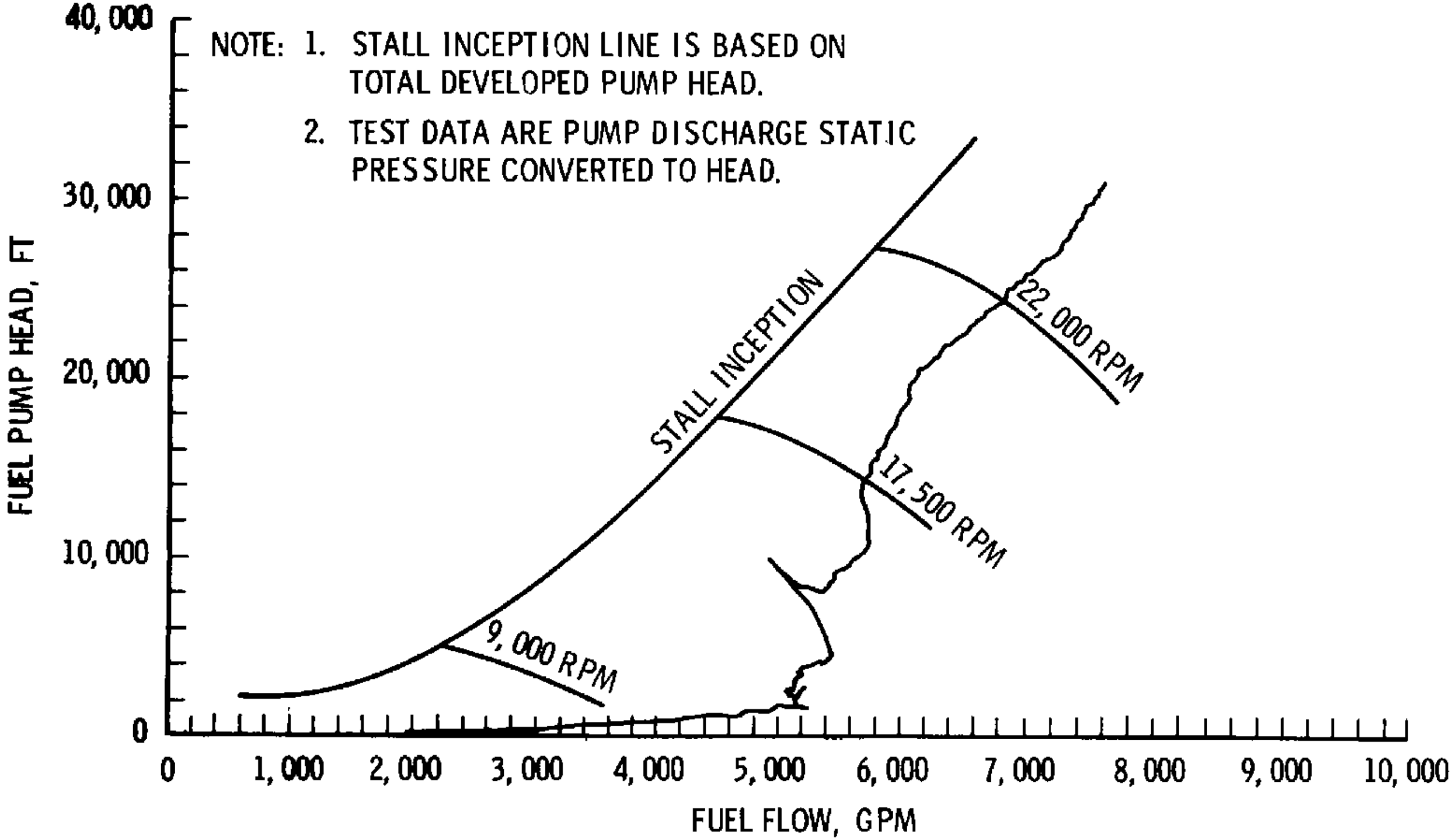


Fig. 24 Fuel Pump Start Transient Performance, Firing 02D

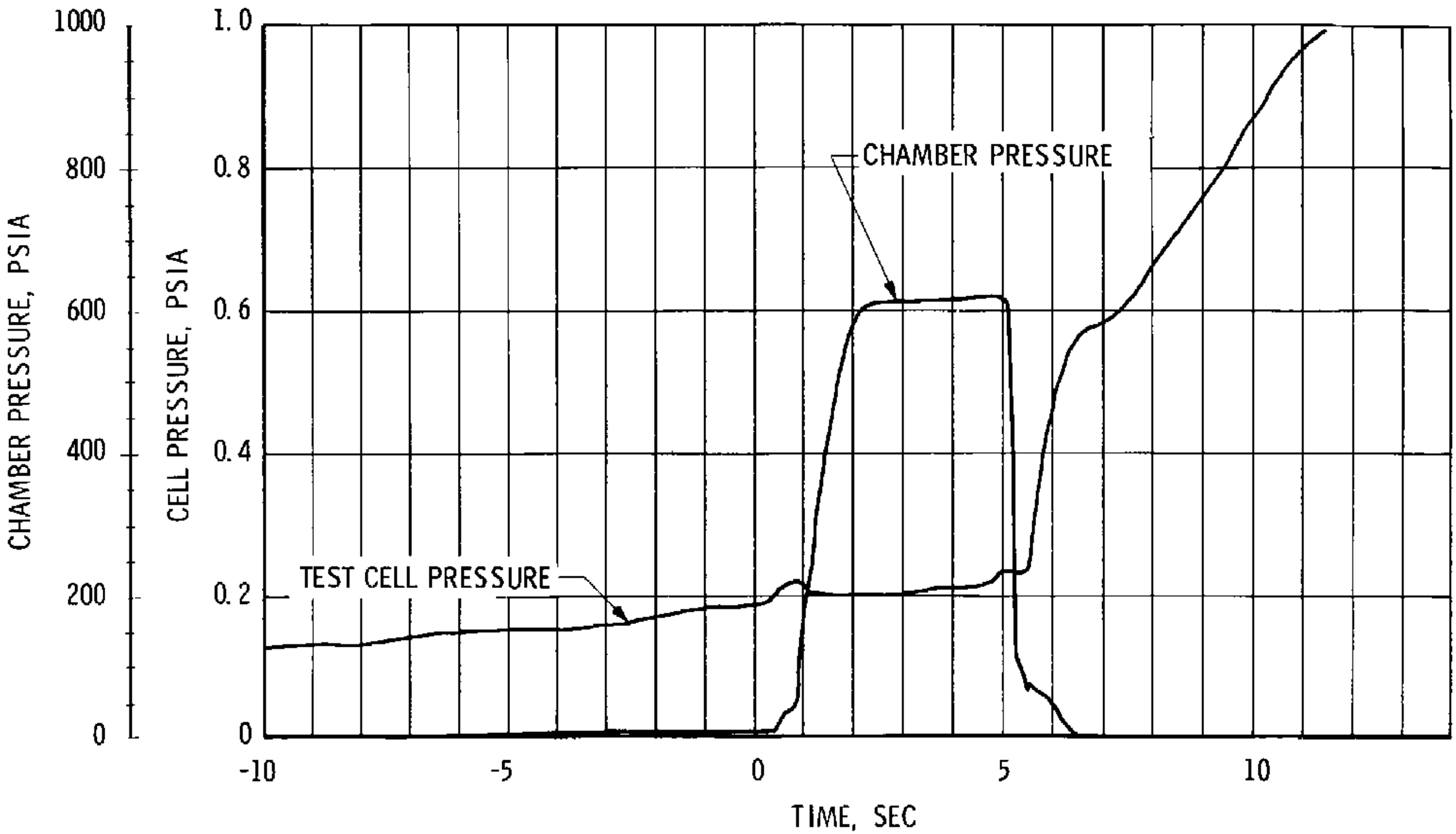


Fig. 25 Engine Chamber and Test Capsule Pressure, Firing 02D

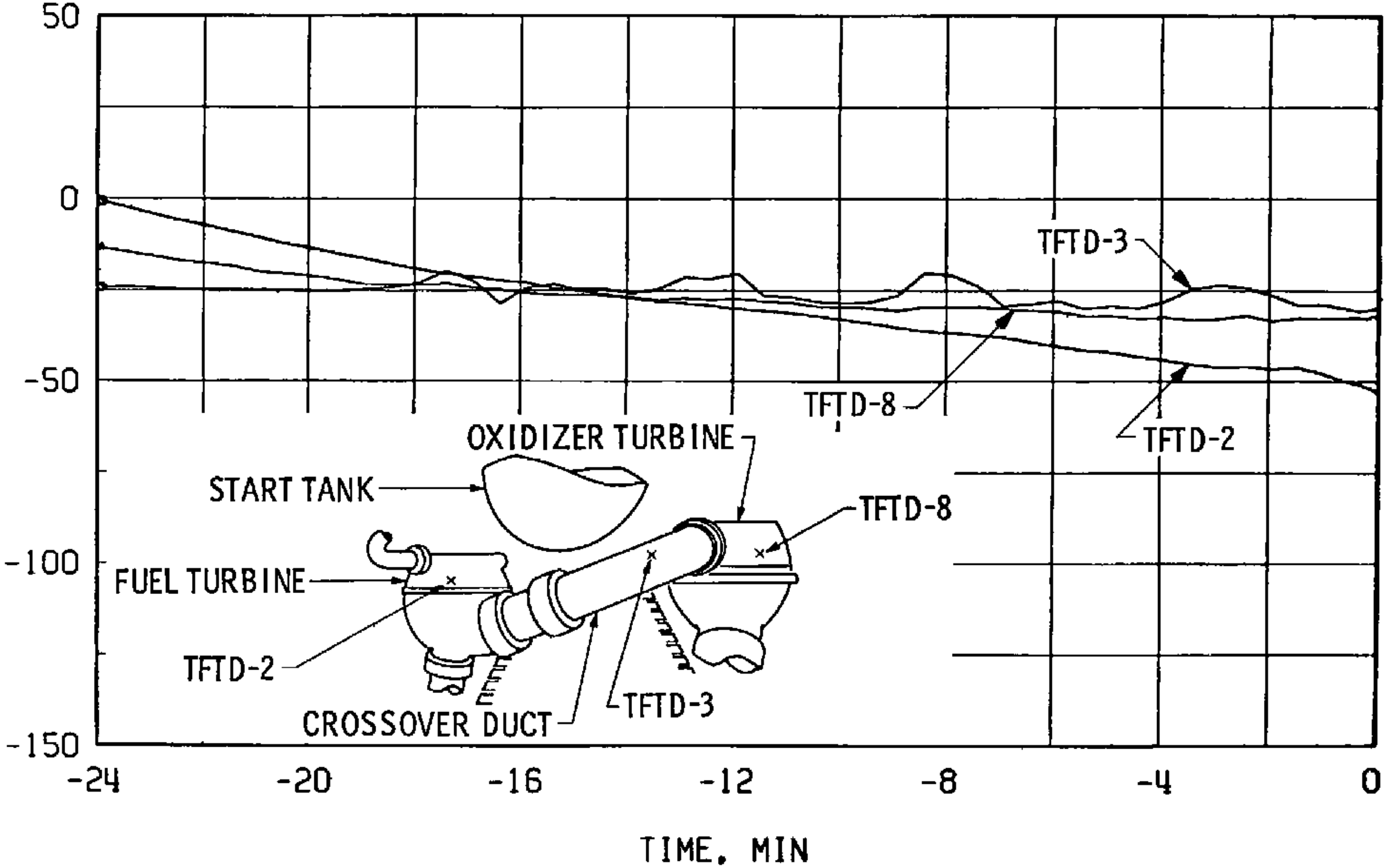


Fig. 26 History of Firing 02E Pre-Fire Temperature Conditioning

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4076553
Thrust Chamber Injector Assembly	208021-11	4084917
Fuel Turbopump Assembly	459000-161	4062324
Oxidizer Turbopump Assembly	458175-71	6623549
Start Tank	303439	0064
Augmented Spark Igniter	206280-21	3661349
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Pneumatic Control Assembly	556947	4079720
Electrical Control Package	502670-11	4081748
Primary Flight Instrumentation Package	703685	4078716
Auxiliary Flight Instrumentation Package	703680	4078718
Main Fuel Valve	409120	4056924
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040	4078714
Start Tank Discharge Valve	306875	4079062
Oxidizer Turbine Bypass Valve	409940	4048489
Propellant Utilization Valve	251351-11	4068944
Main-Stage Control Valve	558069	8313568
Ignition Phase Control Valve	558069	8275775
Helium Control Valve	106012000	342270
Start Tank Vent and Relief Valve	557828-X2	4046446
Helium Tank Vent Valve	106012000	342277
Fuel Bleed Valve	309034	4077749
Oxidizer Bleed Valve	309029	4077746
Augmented Spark Igniter Oxidizer Valve	308880	4077205
P/A Purge Control Valve	557823	4073021
Start Tank Fill/Refill Valve	558000	4079001
Fuel Flowmeter	251225	4077752
Oxidizer Flowmeter	251216	4074114
Fuel Injector Temperature Transducer	NA5-27441	12401
Restartable Ignition Detect Probe	XEOR915389	211

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter	Installation Date	Comments
Gas Generator Oxidizer Supply Line	RD251-4106	0.276 in.	April 28, 1967	
Main Oxidizer Valve Closing Control	410437	8.34 scfm	July 11, 1967	Thermostatic Orifice
Augmented Spark Igniter Oxidizer Supply Line	---	0.110 in.	July 12, 1967	
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.300 in.	May 17, 1967	
Gas Generator Fuel Supply Line	RD251-4107	0.472 in.	May 15, 1967	
Oxidizer Turbine Exhaust Manifold	RD251-9004	9.99 in.	January 18, 1966	Installed on the Engine before Shipment to AEDC

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-01 AND J4-1801-02)

Modification	Completion Date	Description of Modification
RFD*-AEDC 49-67	July 11, 1967	Main Oxidizer Valve with 8.34-scfm Closing Control Thermostatic Orifice. Main Oxidizer Valve Position Indicator Replaced and the Restrictor Check Valve Removed.
RFD-AEDC 50-67	July 12, 1967	Augmented Spark Igniter Oxidizer Orifice Changed from 0.150 to 0.110

*RFD - Rocketdyne Field Directive

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-01 AND J4-1801-02)

Replacement	Completion Date	Component Replacement
UCR*-007961	July 10, 1967	Fuel Turbopump Inlet Temperature Transducer
UCR-007959	July 10, 1967	Gas Generator Outlet Temperature Transducer
UCR-007965	July 12, 1967	Gas Generator Oxidizer Purge Check Valve

*UCR - Unsatisfactory Condition Report

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Time, min[1]: t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 135 psia, 50 - 200°F, (Nominal) 6 scfm at Customer Connect	10 min (t - 70 to t - 60); ←Propellant Drop; 2-min Minimum Following Recirculation; 1 to 3 min
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig, 50 - 200°F, (Minimum) 230 scfm	15 min (to t - 60); 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port COA3)	Nitrogen; 400 - 450 psig, 100 - 200°F, (Nominal) 200 scfm	45 min; On at Engine Cutoff → 10 min
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig, Ambient Temperature, 2800 - 7000 scfm	15 min (to t - 60); Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig, 50 - 200°F, (Nominal) 60 scfm	In Addition to → 15 min (from t - 60)
	Helium; 12 - 14 psig, 50 - 200°F, (Nominal) 10 scfm	On at Engine Cutoff → 10 min
Thrust Chamber Temperature Conditioning	Helium; 1000 psig, -300°F to Ambient, 10 - 20 lb_m/min	15 min (to t - 0)
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia, -298 to -280°F; Fuel; 28 to 46 psia, -424 to -416°F	(t - 60 to t - 0)
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia, -300 to -140°F; Helium; 1700 to 3250 psia, -300 to -140°F	46 min (to t - 0)
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	[3] (t - 70 to t - 0)
Main Oxidizer Valve Actuator Temperature Conditioning	Helium; -300°F to Ambient	[2] (t - 70 to t - 0)
Main Oxidizer Valve Closing Control Line (Conditioning)	Helium; -300°F to Ambient	[3] (t - 70 to t - 0)
Pneumatic Regulator Temperature Conditioning	Helium; -300°F to Ambient	[2] (t - 70 to t - 0)

[1] Times are adjusted as required for one- and two-orbit restart simulation firings.

[2] Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

[3] Component conditioning to be maintained within limits for last 15 min before engine start.

TABLE VI

SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-02		02A Target	02A Actual	02B Target	02B Actual	02C Target	02C Actual	02D Target	02D Actual	02E Target	02E Actual
Firing Date / Time of Day, hr		7/14/67 / 1258		7/14/67 / 1334		7/14/67 / 1641		7/14/67 / 1702		7/14/67 / 1801	
Pressure Altitude at Engine Start, ft		-	97,000	-	104,000	-	105,000	-	104,000	-	106,000
Firing Duration, sec ①		30	30.073	5	5.086	30	30.072	5	5.086	④	0.485
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	28.0^{+1}_{-0}	28.3	37.0	36.5	28.0^{+1}_{-0}	27.8	37.0	35.8	46.0 ± 1.0	43.0
	Temperature, °F	420.4 ± 0.4	-420.4	-420.0 ± 0.4	-420.6	-420.4 ± 0.4	-420.3	-420.0 ± 0.4	-419.7	-421.1 ± 0.4	-420.2
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	48.0 ± 1.0	47.7	41.0 ± 1.0	40.1	48.0 ± 1.0	47.9	41.0 ± 1.0	40.3	35.0 ± 1.0	35.2
	Temperature, °F	-295.3 ± 0.4	-295.8	-295.3 ± 0.4	-295.7	-295.3 ± 0.4	-296.0	-295.3 ± 0.4	-295.3	-290.4 ± 0.4	-290.2
Start Tank Conditions at Engine Start	Pressure, psia	400 ± 10	1395	1300 ± 10	1297	1350 ± 10	1248	1315 ± 10	1316	1250 ± 10	1244
	Temperature, °F	-200 ± 10	-203	-210 ± 10	-202	-200 ± 10	-202	-225 ± 10	219	-140 ± 10	-142
Helium Tank Conditions at Engine Start	Pressure, psia	-	2258	-	2200	-	2426	-	2318	-	2588
	Temperature, °F	-	-207	-	-305	-	-204	-	-221	-	-146
Thrust Chamber Temperature Conditions at Engine Start/ t_0, °F	Throat	-80 ± 15	115 / -121	-	-28 / -111	-80 ± 15	-69 / -94	-	-40 / -117	-80 ± 15	-90 / -103
	Average	-	-91 / -147	-	8 / -218	-	-59 / -112	-	8 / -222	-	105 / -183
Crossover Duct Temperature at Engine Start, °F ②	TFTD-2	-20 ± 15	-65	-	352	-20 ± 15	-56	-	451	-20 ± 15	-54
	TFTD-3	-20 ± 15	-17	125^{+15}_{-0}	109	-20 ± 15	-22	165^{+15}_{-0}	176	-20 ± 15	-30
	TFTD-8	-20 ± 15	-30	-	310	-20 ± 15	-285	-	394	-20 ± 15	-32
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F ②		-100 ± 10	-96	-150 ± 10	-148	-100 ± 10	-113	-150 ± 10	-151	-	-344
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F ②		-175 ± 10	166	-175 ± 10	-178	-175 ± 10	-182	-175 ± 10	-157	-	-175
Pneumatic Control Package Temperature at Engine Start, °F ③		-100 ± 10	-116	-150 ± 10	-170	-100 ± 10	-123	-150 ± 10	-175	-	-89
Fuel Lead Time, sec ①		3.0	3.000	8.0	7.980	3.0	3.000	8.0	7.982	3.0	3.003
Propellant in Engine Time, min		60	116	At Engine Start	10	60	86	At Engine Start	11	60	58
Propellant Recirculation Time, min		10	11	10	10	10	10	10	12	10	10
Start Sequence Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-1	-	-75.8	-	124.9	-	-114.7	-	-94.3	-	-
	TOBS-2	-	-48.6	-	- 42.6	-	- 82.7	-	-42.7	-	-
	TOBS-3	-	-251.6	-	-106.9	-	-120.6	-	-248.4	-	-
Vibration Safety Counts Duration (msec) and Occurrence Time (sec) from t_0 ①		- / -	14 / 0.975	- / -	0 / 0	- / -	0 / 0	- / -	35 / 0.965	- / -	- / -
Gas Generator Outlet Temperature, °F	Initial Peak	-	2080	-	1690	-	1840	-	2100	-	-
	Overshoot	-	-	-	-	-	-	-	-	-	-
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) ①		-	0.968	-	0.992	-	0.982	-	0.956		-
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) ①		-	0.979	-	1.053	-	1.040	-	0.974	-	-
Main Stage Pressure No. 2, sec (Ref. t_0) ①		-	1.596	-	1.709	-	1.596	-	1.617	-	-
550-psia Chamber Pressure Attained, sec (Ref. t_0) ①		-	1.854	-	2.040	-	1.848	-	1.958	-	-
Propellant Utilization Valve Position at Engine Start, deg / Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / -	Open / -	Null / Closed	Null / Closed	Open / -	Open / -	Null / -	Null / -

Notes: ① Data reduced from oscillogram

② Component conditioning to be maintained within limits for last 15 min before engine start.

③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

④ Test to be terminated at expiration of ignition phase timer.

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start																							
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
02A	0	0.156	0.146	0.444	0.098	0.274	-3.000	0.058	0.045	0.444	0.052	0.047	0.444	0.531	1.766	0.444	0.090	0.058	0.444	0.101	0.080	0.444	0.291	0.320
02B	0	0.157	0.142	0.447	0.098	0.280	-7.977	0.060	0.045	0.447	0.050	0.053	0.447	0.613	1.652	0.447	0.091	0.058	0.447	0.104	0.084	0.447	0.275	0.310
02C	0	0.155	0.145	0.443	0.098	0.276	-3.000	0.056	0.065	0.443	0.053	0.048	0.443	0.611	1.677	0.443	0.090	0.057	0.443	0.188	0.080	0.443	0.270	0.310
02D	0	0.152	0.150	0.445	0.095	0.273	-7.980	0.057	0.048	0.445	0.050	0.050	0.445	0.531	1.785	0.445	0.090	0.057	0.445	0.190	0.076	0.445	0.270	0.297
02E	0	0.158	0.143	0.446	---	---	-3.001	0.057	0.070	0.446	---	---	0.446	---	---	0.446	---	---	0.446	---	---	0.446	---	---
Pre-Fire Final Sequence	0	0.098	0.113	0.447	0.093	0.250	-3.000	0.042	0.066	0.447	0.048	0.043	0.447	0.584	1.748	0.447	0.074	0.044	0.447	0.136	0.053	0.447	0.213	0.293

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
02A	30.073	0.120	0.341	30.073	0.080	0.197	30.073	0.070	0.222	30.073	0.020	0.030	30.073	0.325	1.396
02B	5.086	0.110	0.322	5.086	0.070	0.182	5.086	0.078	0.188	5.086	0.020	0.031	5.086	0.270	0.728
02C	30.072	0.115	0.327	30.072	0.084	0.200	30.072	0.067	0.222	30.072	0.018	0.027	30.072	0.280	0.953
02D	5.086	0.111	0.320	5.086	0.070	0.180	5.086	0.073	0.194	5.086	0.020	0.034	5.086	0.282	0.657
02E	0.485	0.105	0.325	0.485	---	---	0.485	---	---	0.485	---	---	0.485	---	---
Pre-Fire Final Sequence	---	0.088	0.244	---	0.062	0.130	---	0.086	0.044	---	0.041	0.046	---	0.231	0.601

Notes: 1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve open or closed solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscilloscogram.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number: J4-1801-		02A		02C	
Time, sec		29.5		29.5	
		Site	Normalized	Site	Normalized
Overall Engine Performance	Thrust, lb	227,122	225,871	227,781	225,825
	Chamber Pressure, psia	770.8	759.4	770.7	759.3
	Oxidizer-to-Fuel Mixture Ratio	5.747	5.699	5.783	5.725
	Oxidizer Flow, lb_m/sec	460.2	452.7	461.0	452.8
	Fuel Flow, lb_m/sec	80.1	79.4	79.3	79.1
	Total Weight Flow, lb_m/sec	540.3	531.6	540.8	531.8
Thrust Chamber Performance	Mixture Ratio	5.964	5.918	6.003	5.945
	Total Weight Flow, lb_m/sec	533.3	524.6	533.8	524.9
	Characteristic Velocity, ft/sec	7921.7	7933.6	7914.2	7929.2
Fuel Turbopump Performance	Pump Efficiency, percent	72.7	72.7	73.0	73.0
	Pump Speed, rpm	26,611	26,342	26,643	26,336
	Turbine Efficiency, percent	---	---	---	---
	Turbine Pressure Ratio	---	---	---	---
	Turbine Inlet Temperature, °F	1285.7	1255.2	1290.9	1256.2
	Turbine Weight Flow, lb_m/sec	6.98	6.93	6.98	6.93
Oxidizer Turbopump Performance	Pump Efficiency, percent	80.4	80.3	80.4	80.3
	Pump Speed, rpm	8598	8534	8603	8544
	Turbine Efficiency, percent	---	---	---	---
	Turbine Pressure Ratio	---	---	---	---
	Turbine Inlet Temperature, °F	838.8	816.5	843.2	818.0
	Turbine Weight Flow, lb_m/sec	5.34	5.30	6.31	6.26
Gas Generator Performance	Mixture Ratio	0.991	0.973	0.994	0.973
	Chamber Pressure, psia	659.2	651.2	659.6	651.7

Site - Test Data
Normalized - Test Data Corrected to Standard Pump Inlet and Engine Ambient Vacuum Conditions

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC Test J4-1801-02 is tabulated in Table III-I. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
LIST OF ENGINE INSTRUMENTATION

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
	Sparks							
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2					x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Forces		lbf					
FSP-1	Side Load (Pitch)		±20,000	x		x		
FSY-1	Side Load (Yaw)		±20,000	x		x		
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCASI-2	Augmented Spark Igniter Chamber	IG1	0 to 1000	x				
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJCG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0 to 1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PGBNI	Bypass Nozzle Inlet	TG8	0 to 200	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure							
POJCG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 115	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to +50	x			x	
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				

TABLE III-1 (Continued)

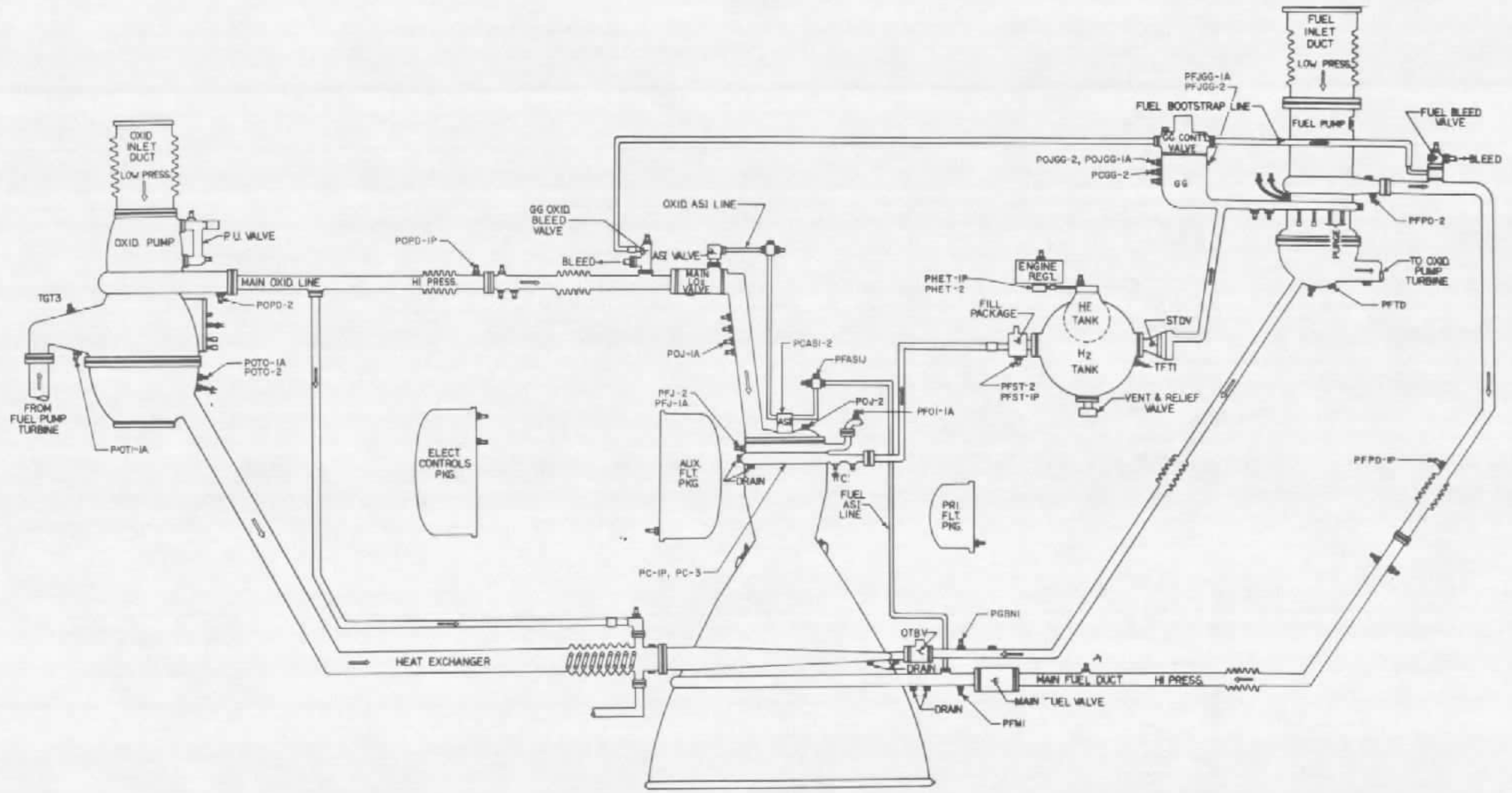
AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-1R	Fuel Turbine Discharge Collector		-200 to +900	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TMOVC	Main Oxidizer Valve Actuator Conditioning		-325 to +200	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-5	Oxidizer Bootstrap Line		-300 to +250	x				
TOBSCI	Oxidizer Bootstrap Conditioning Inlet		0 to 100	x				
TOBSCO	Oxidizer Bootstrap Conditioning Outlet		0 to 100	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				

TABLE III-1 (Continued)

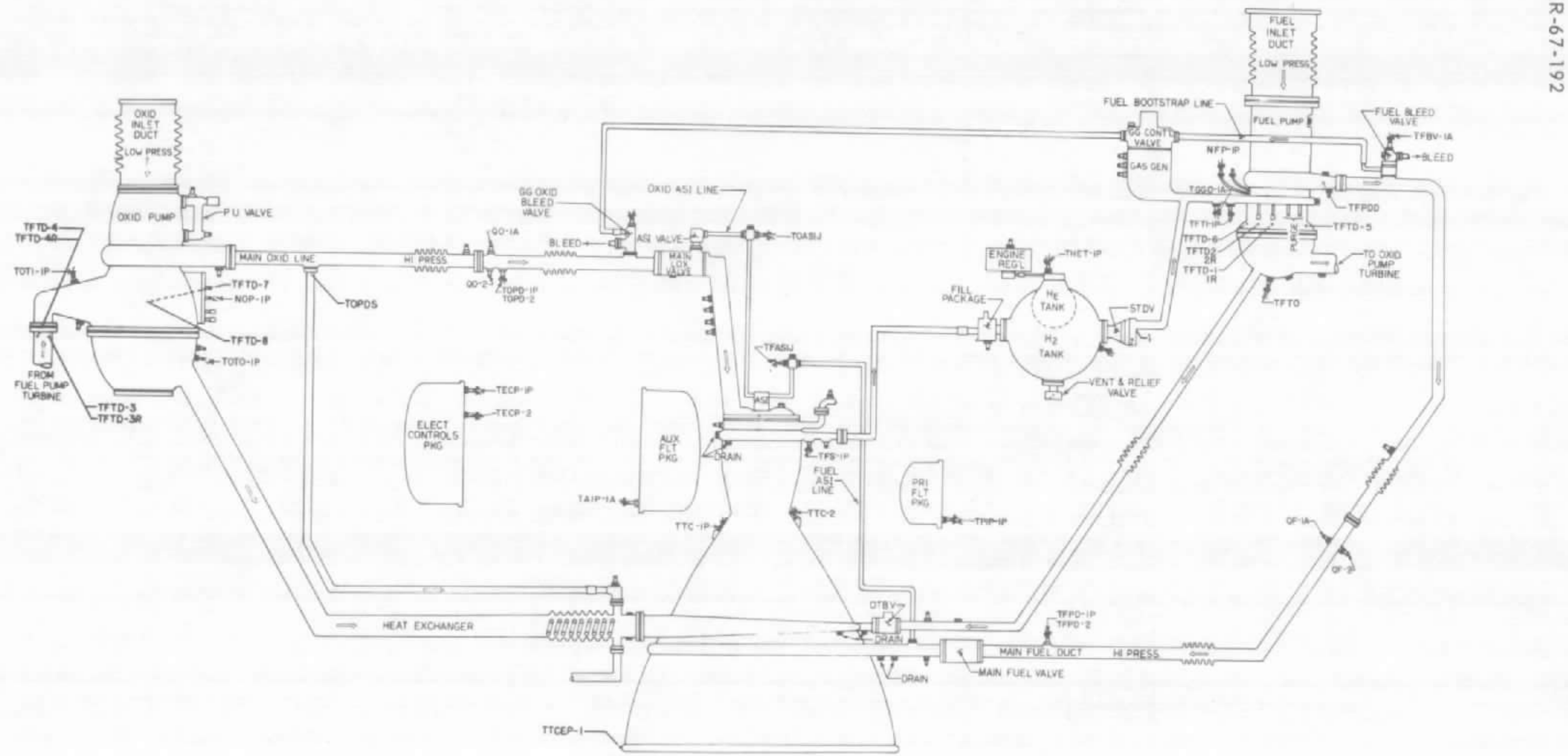
AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPDS	Oxidizer Pump Discharge Skin		-300 to -100	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPPC	Pneumatic Package Conditioning		-325 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				

TABLE III-1 (Concluded)

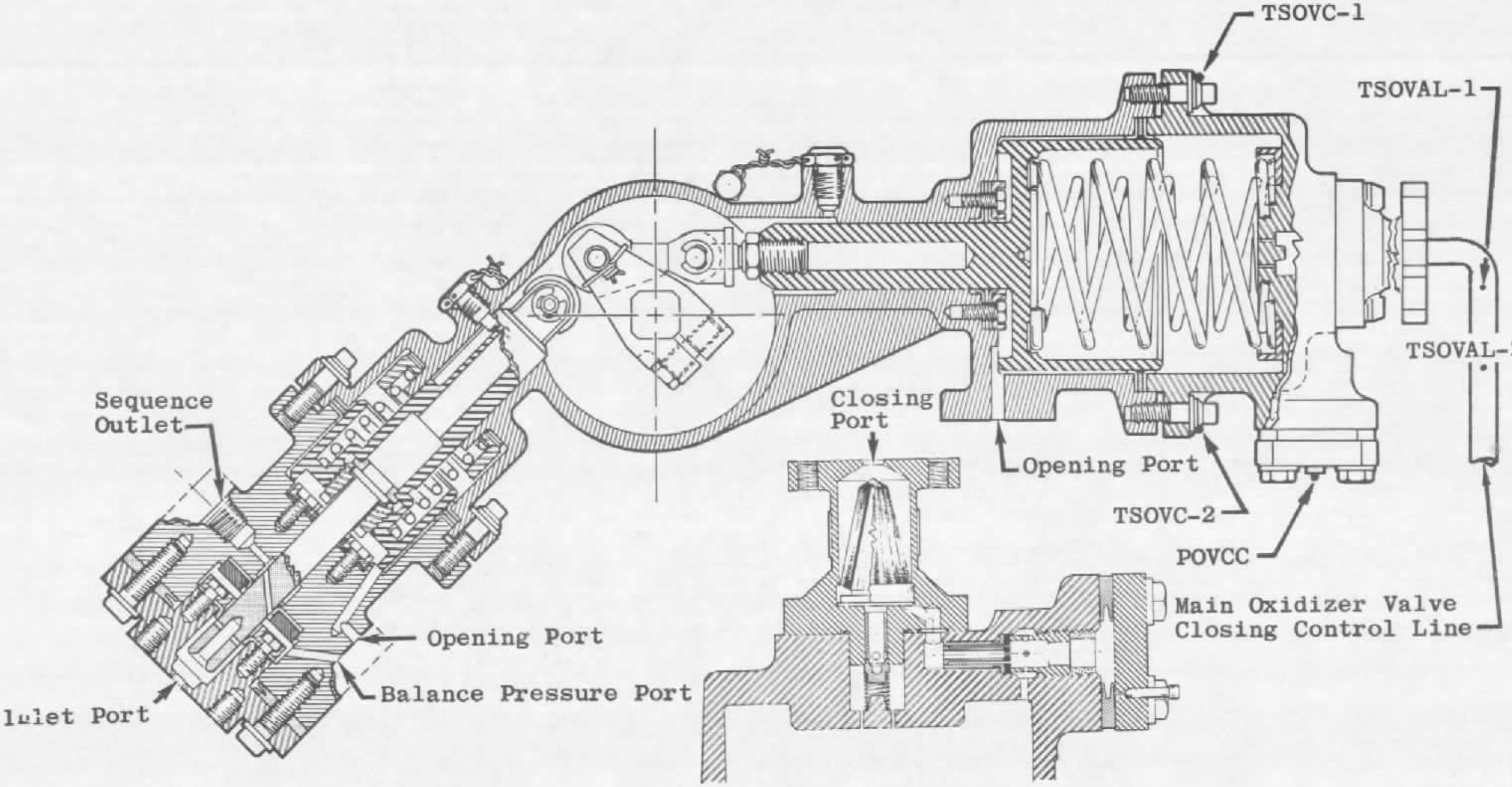
AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSOVAL-2	Oxidizer Valve Closing Control Line		-200 to +100	x			x	
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVCC	Start Tank Discharge Valve Closing Control Port		-350 to +100	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		g					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		Volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				



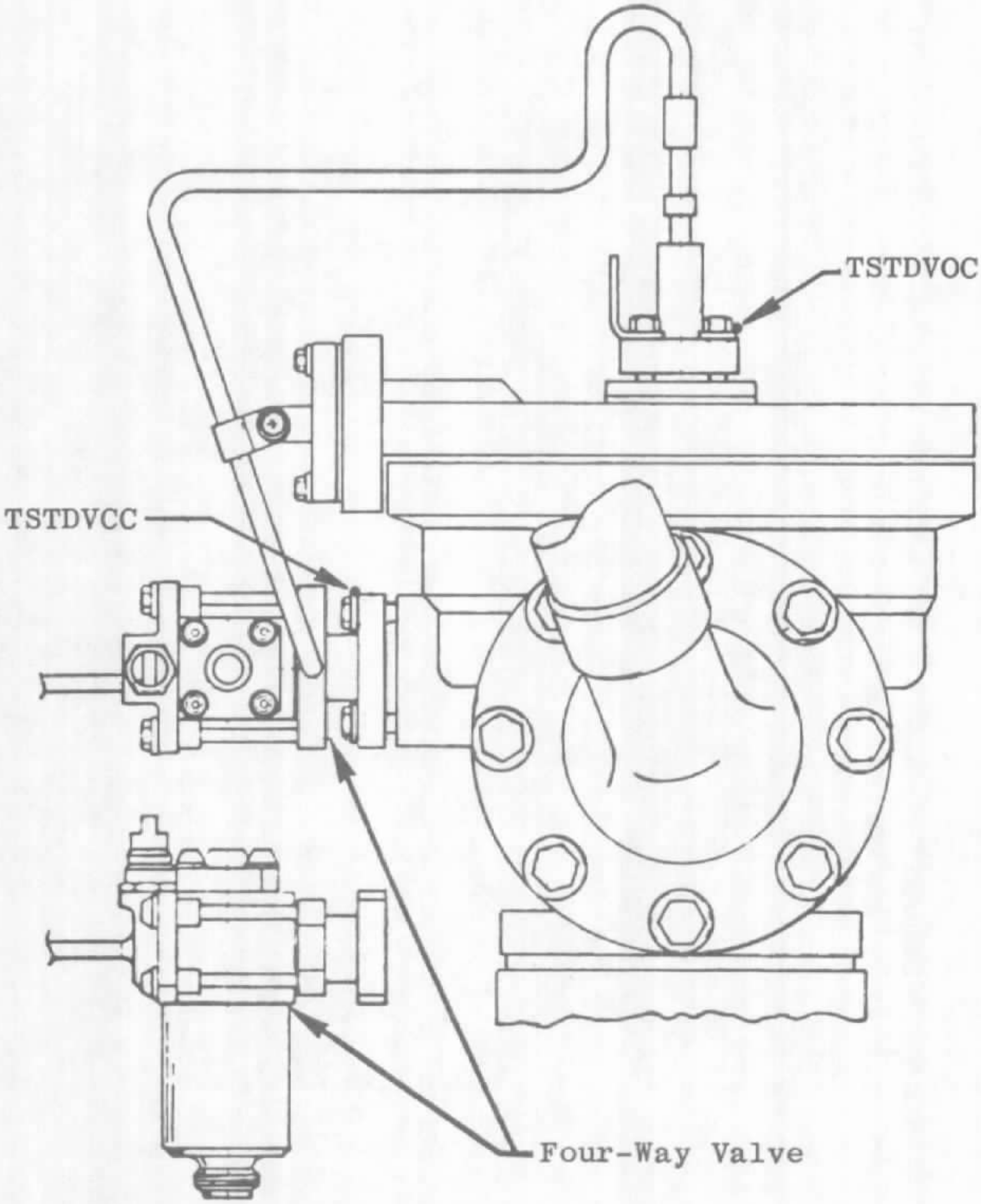
a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations



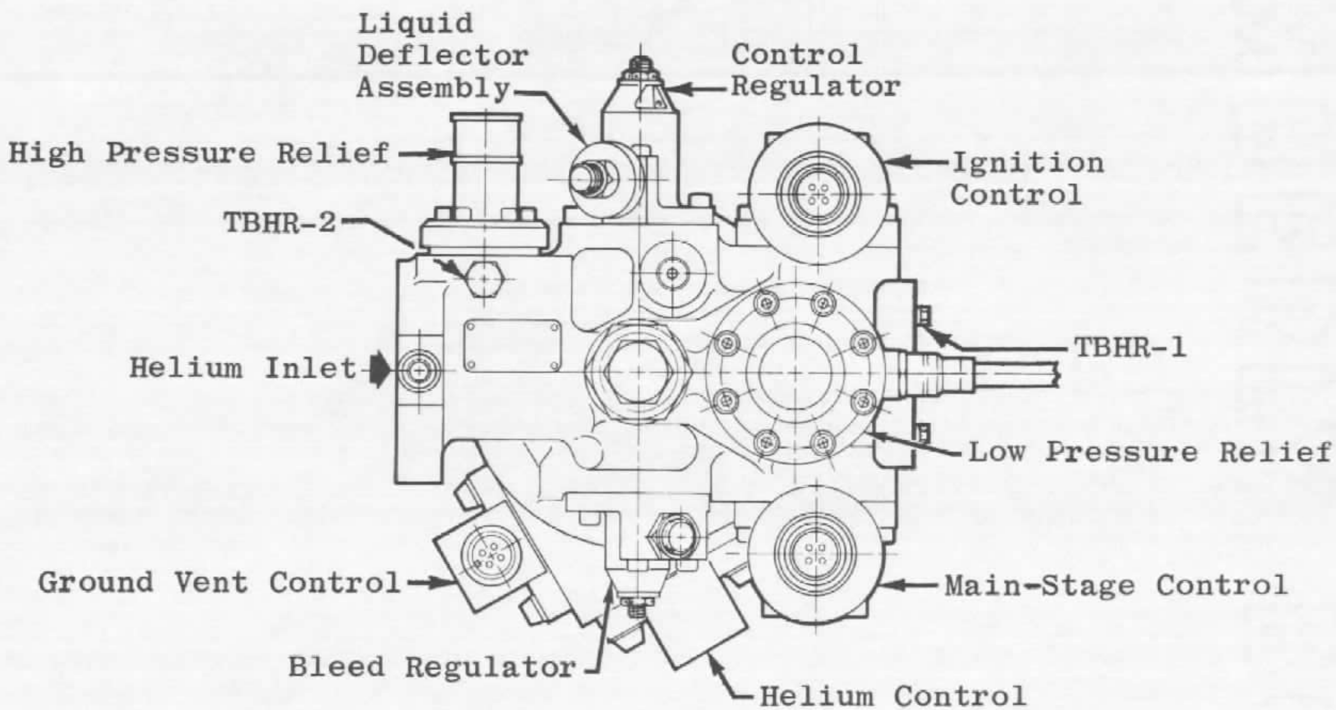
b. **Engine Temperature, Flow, and Speed Instrumentation Locations**
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued

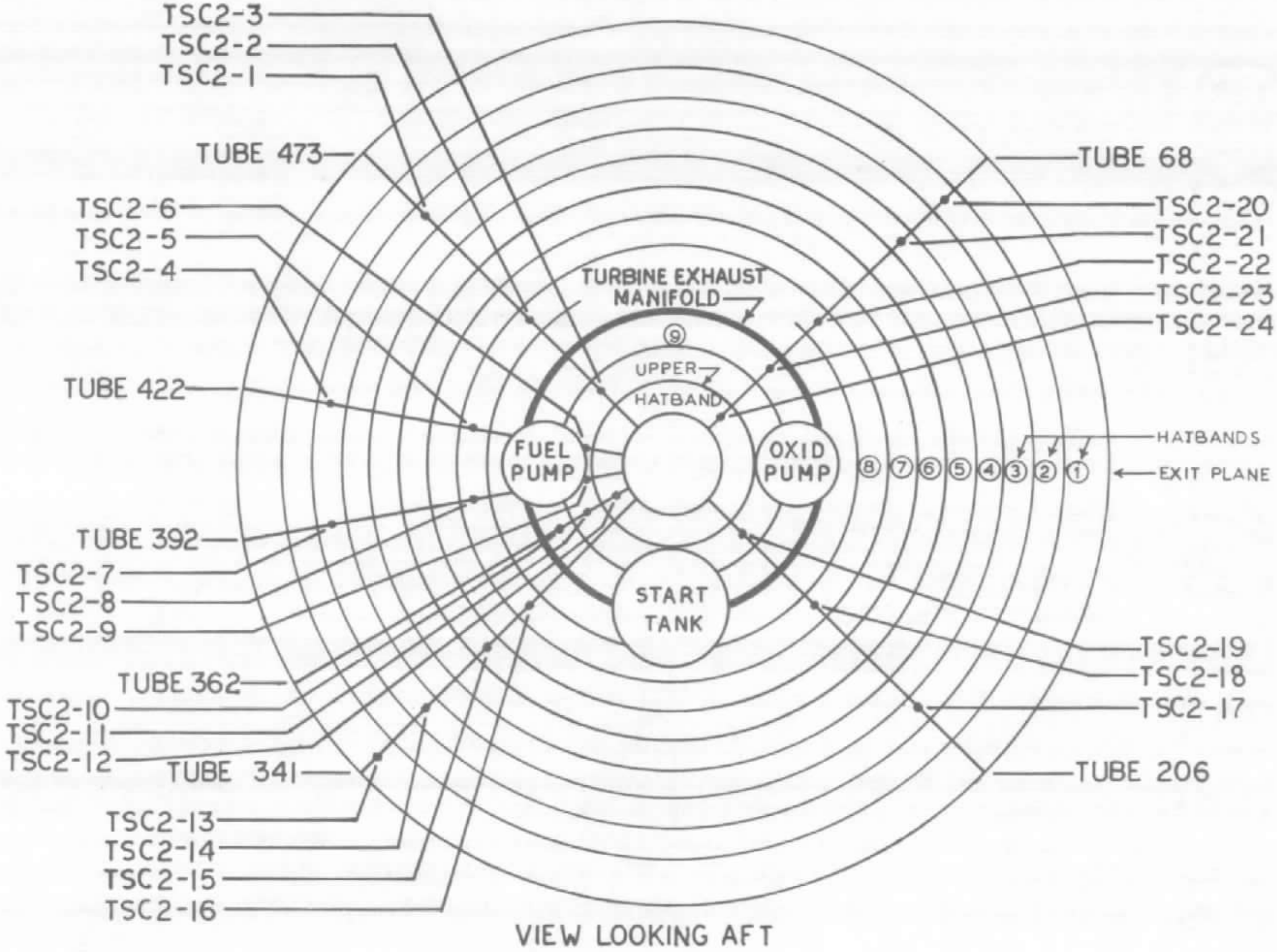


d. Start Tank Discharge Valve
Fig. III-1 Continued



Top View

e. Helium Regulator
Fig. III-1 Continued



f. Thrust Chamber
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C^*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_o	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{\dot{W}_{EO}}{\dot{W}_{EF}}$$

$$\dot{W}_{EO} = \dot{W}_{OM} - \dot{W}_{XO}$$

$$\dot{W}_{EF} = \dot{W}_{FM} - \dot{W}_{XF}$$

$$\dot{W}_E = \dot{W}_{EO} + \dot{W}_{EF}$$

Thrust Chamber

$$r_C = \frac{\dot{W}_{CO}}{\dot{W}_{CF}}$$

$$\dot{W}_{CO} = \dot{W}_{OM} - \dot{W}_{XO} - \dot{W}_{GO}$$

$$\dot{W}_{CF} = \dot{W}_{FM} - \dot{W}_{XF} - \dot{W}_{GF}$$

$$\dot{W}_{XO} = 0.8 \text{ lb/sec}$$

$$\dot{W}_{XF} = 1.8 \text{ lb/sec}$$

$$\dot{W}_{GO} = \dot{W}_T - \dot{W}_{GF}$$

$$\dot{W}_{GF} = \frac{\dot{W}_T}{1 + r_G}$$

$$\dot{W}_T = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$\dot{W}_C = \dot{W}_{CO} - \dot{W}_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{\dot{W}_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,^\circ\text{F}$$

$$T_{IF} = -422.547\,^\circ\text{F}$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values } f\,(P,T)$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ln R = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \Delta h_f W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \quad H_2}{\gamma_{H2-1}} (P_{RNC})^{\frac{2}{\gamma_{H2}}} \right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2-1}}{\gamma_{H2}}} \right] \frac{A_{NB} \quad P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[1 + K_8 \left(\frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H2R}}{D^4{}_{TEF} M_{H2}} \left(\frac{\gamma_{H2-1}}{\gamma_{H2}} \right) \right]^{\frac{\gamma_{H2}}{\gamma_{H2-1}}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 - B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^{5}$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 - K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4{}_{TIF}\, M_{H1}} \quad \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{H1R} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\ (T_{H1R}, r_G)$$

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)*

Arnold Engineering Development Center,
ARO, Inc., Operating Contractor,
Arnold Air Force Station, Tennessee

2a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

2b. GROUP: N/A

3 REPORT TITLE

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-02)

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

July 14, 1967 - Interim Report

5 AUTHOR(S) *(First name, middle initial, last name)*

D. E. Franklin, ARO, Inc.

6 REPORT DATE	7a. TOTAL NO OF PAGES	7b NO OF REFS
December 1967	94	5

8a. CONTRACT OR GRANT NO AF40(600)-1200

b. PROJECT NO 9194

c. System 921E

d.

9a. ORIGINATOR'S REPORT NUMBER(S): AEDC-TR-67-192

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*: N/A

10 DISTRIBUTION STATEMENT Subject to special export controls; transmittal to foreign governments or foreign nationals requires approval of NASA, MSFC (I-E-J), Huntsville, Alabama. Transmittal outside of DOD requires approval of NASA, MSFC (I-E-J), Huntsville, Alabama.

11 SUPPLEMENTARY NOTES

Available in DDC.

12 SPONSORING MILITARY ACTIVITY

NASA, MSFC (I-E-J),
Huntsville, Alabama

13 ABSTRACT

Four firings, and one engine start to expiration of the ignition phase timer, of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4. The firings were accomplished during test period J4-1801-02 at pressure altitudes from 97,000 to 106,000 ft at engine start. The objectives of the test were to evaluate S-IVB/S-V start condition effects on (1) gas generator and augmented spark igniter chamber ignition characteristics and (2) fuel pump stall characteristics during start tank blowdown for J-2 engine J-2052. Engine thermal conditions predicted for the J-2 engine flight configuration first burn, and restarts after one and two orbits, were simulated. Satisfactory engine operation was obtained. The accumulated engine firing duration was 70.8 sec.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, MSFC (I-E-J), Huntsville, Alabama.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
J-2 rocket engine						
altitude tests						
ignition						
stall						
Saturn						
Apollo						